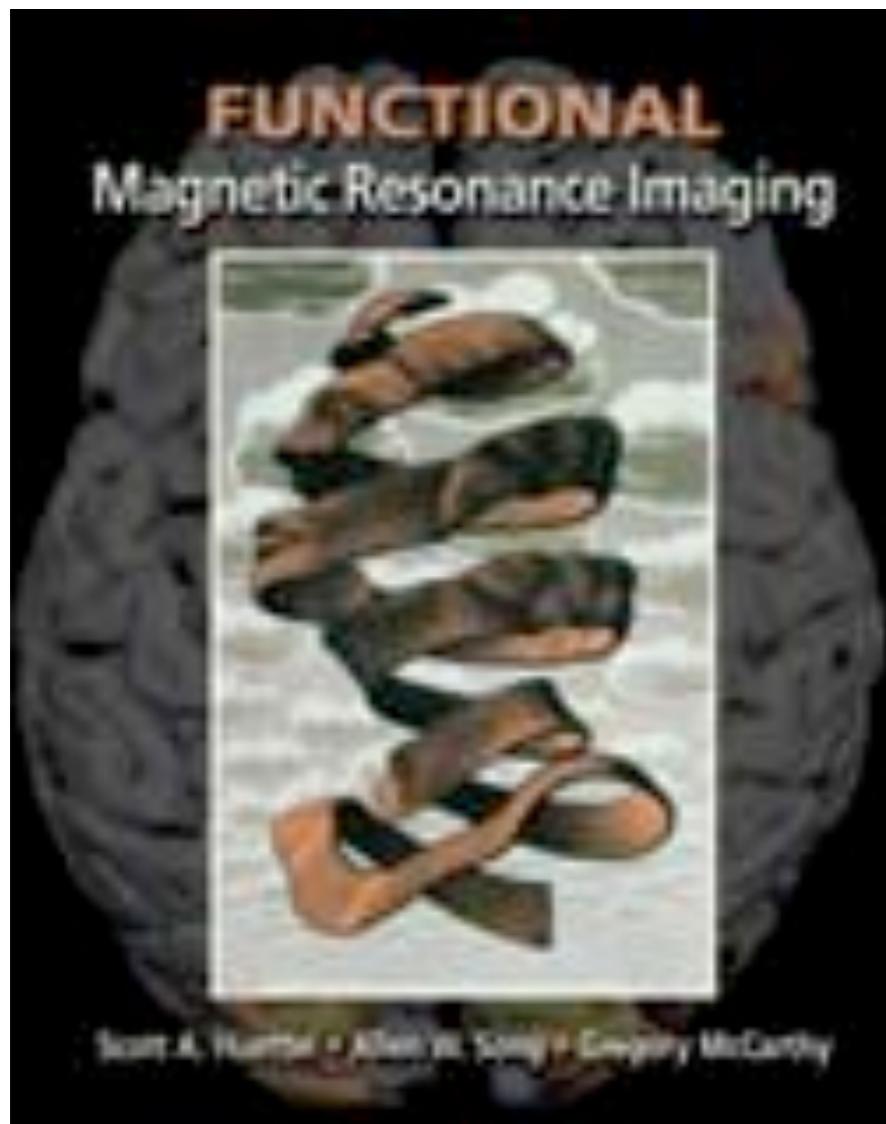


The MRI Scanner Kicking the Tires

Souheil Inati
fMRI Course
Jun. 12, 2013

Interrupt early and often.

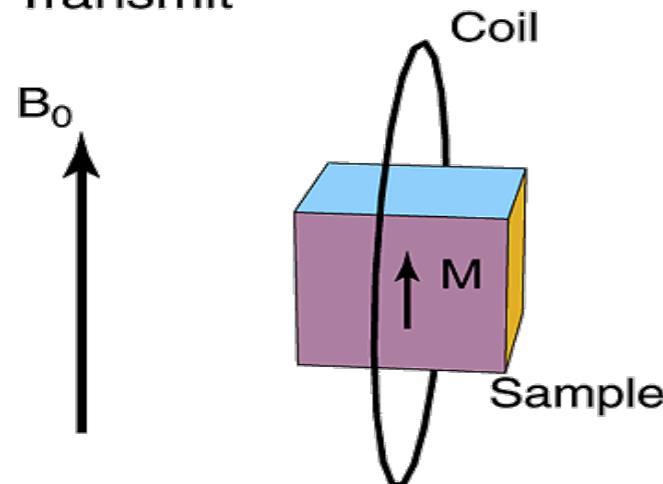


Most figures taken from
Functional Magnetic
Resonance Imaging by
Huettel, Song and McCarthy

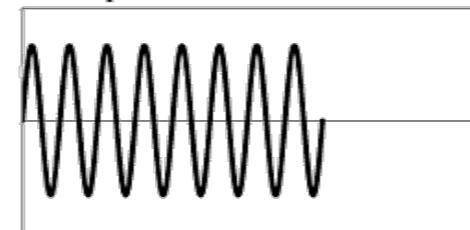
some from Understanding
Physics by Cummings, Laws,
Redish, and Clooney

NMR Spectroscopy

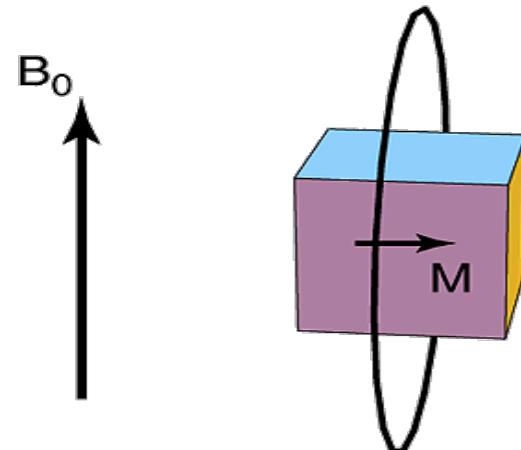
Transmit



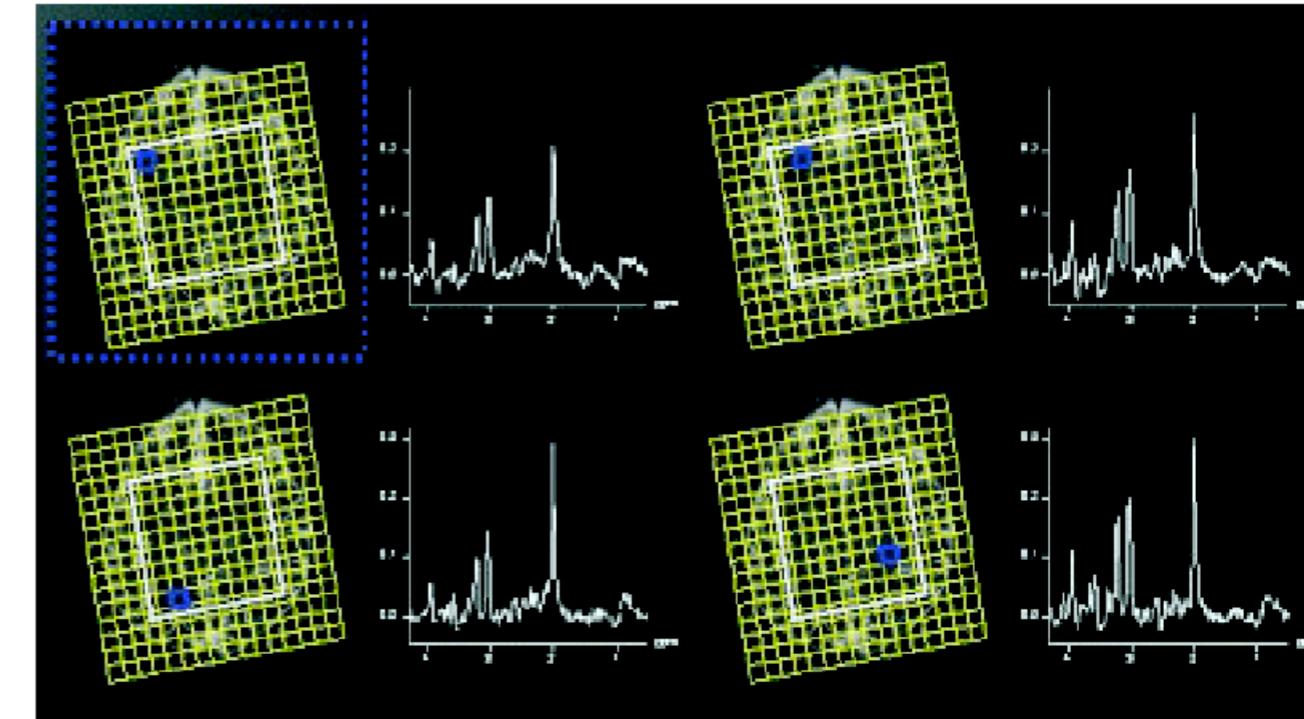
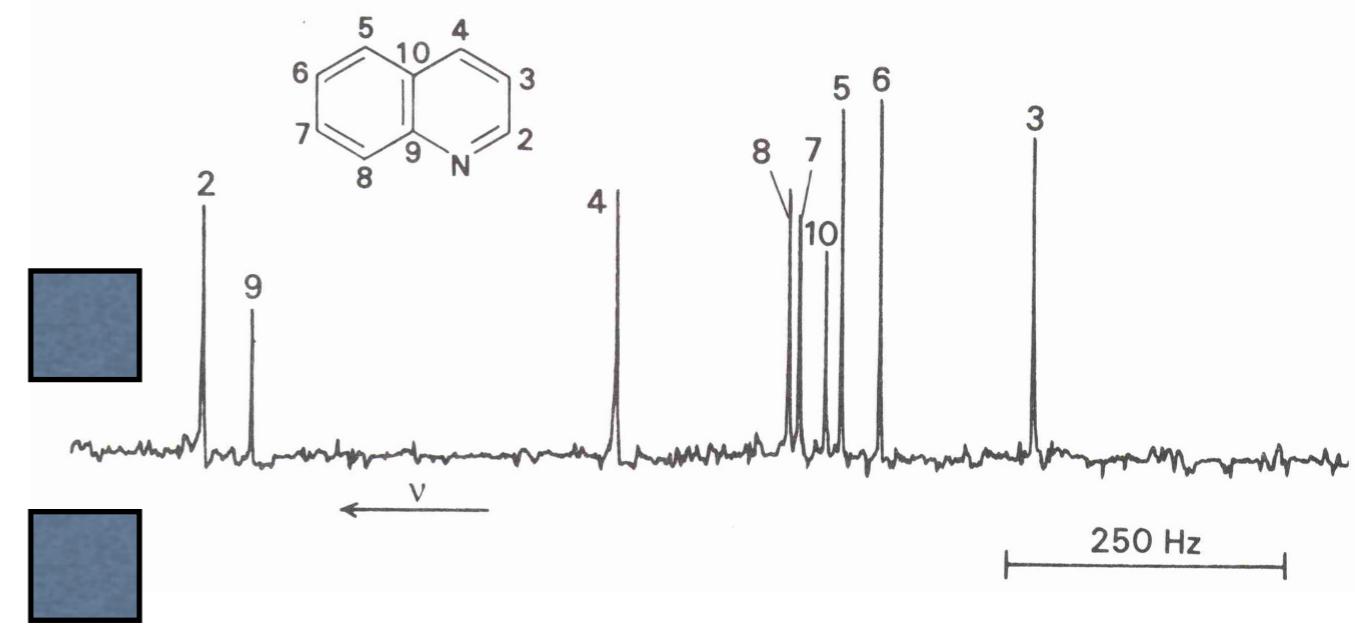
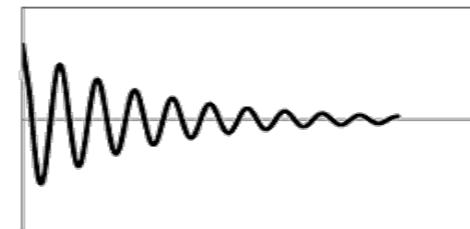
RF pulse



Receive

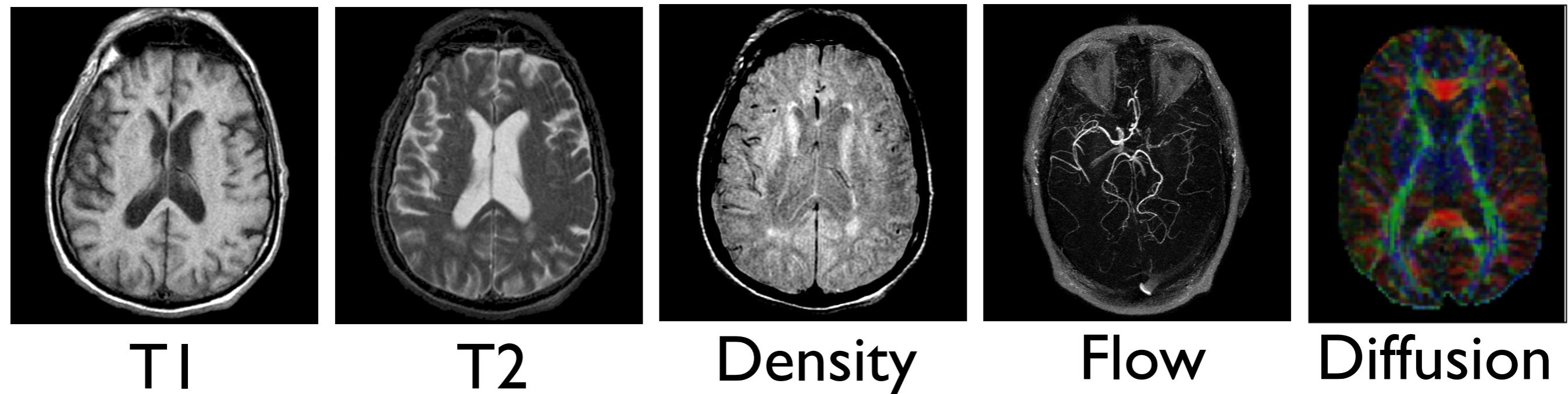


NMR signal



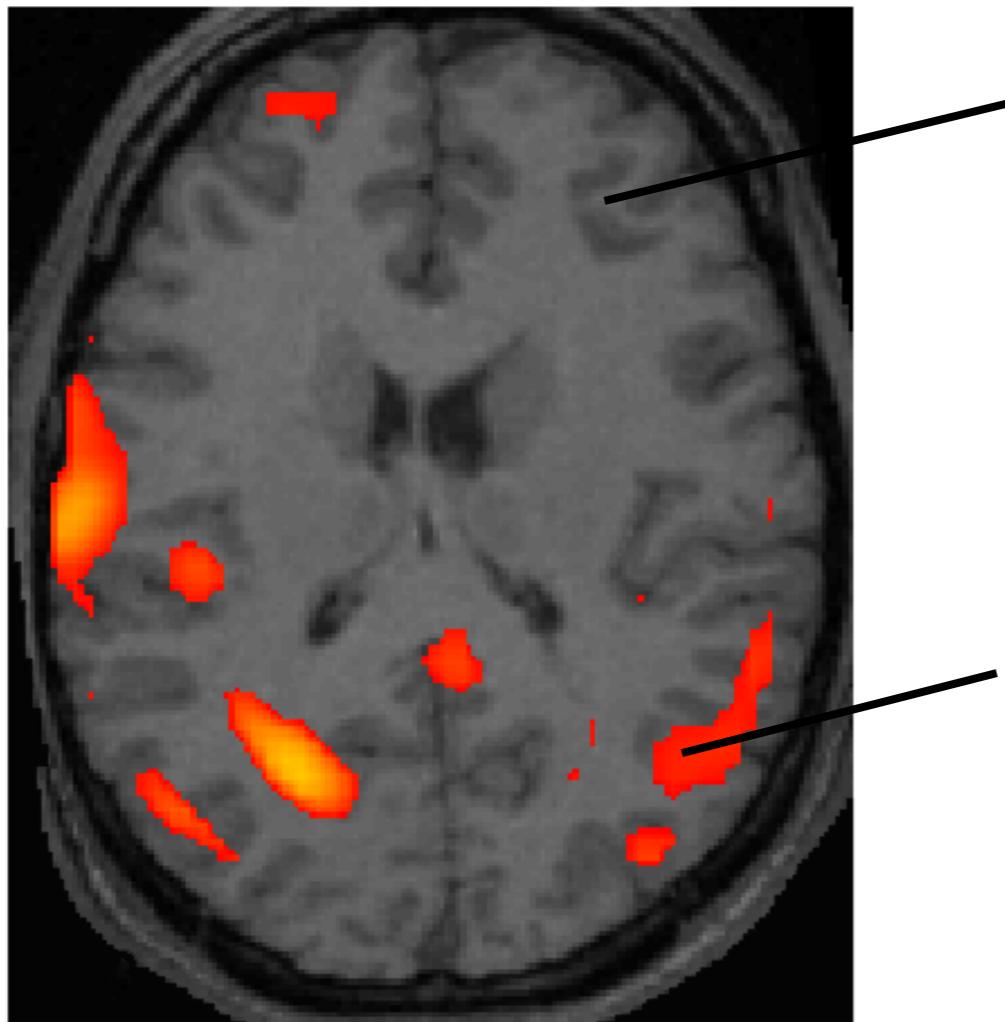
Direct measure of chemical composition

Bread and Butter Clinical MRI



Images of water density weighted by local
microscopic environment

Measure Cognitive Function



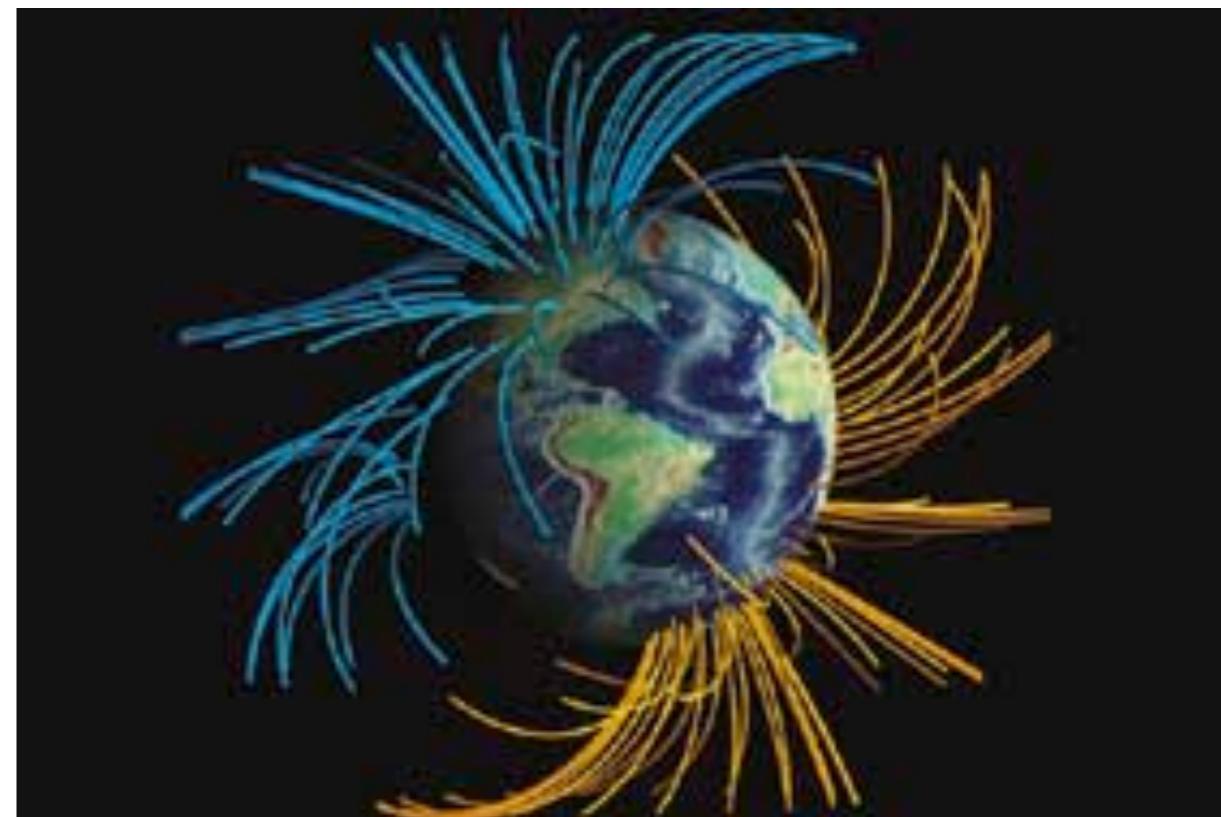
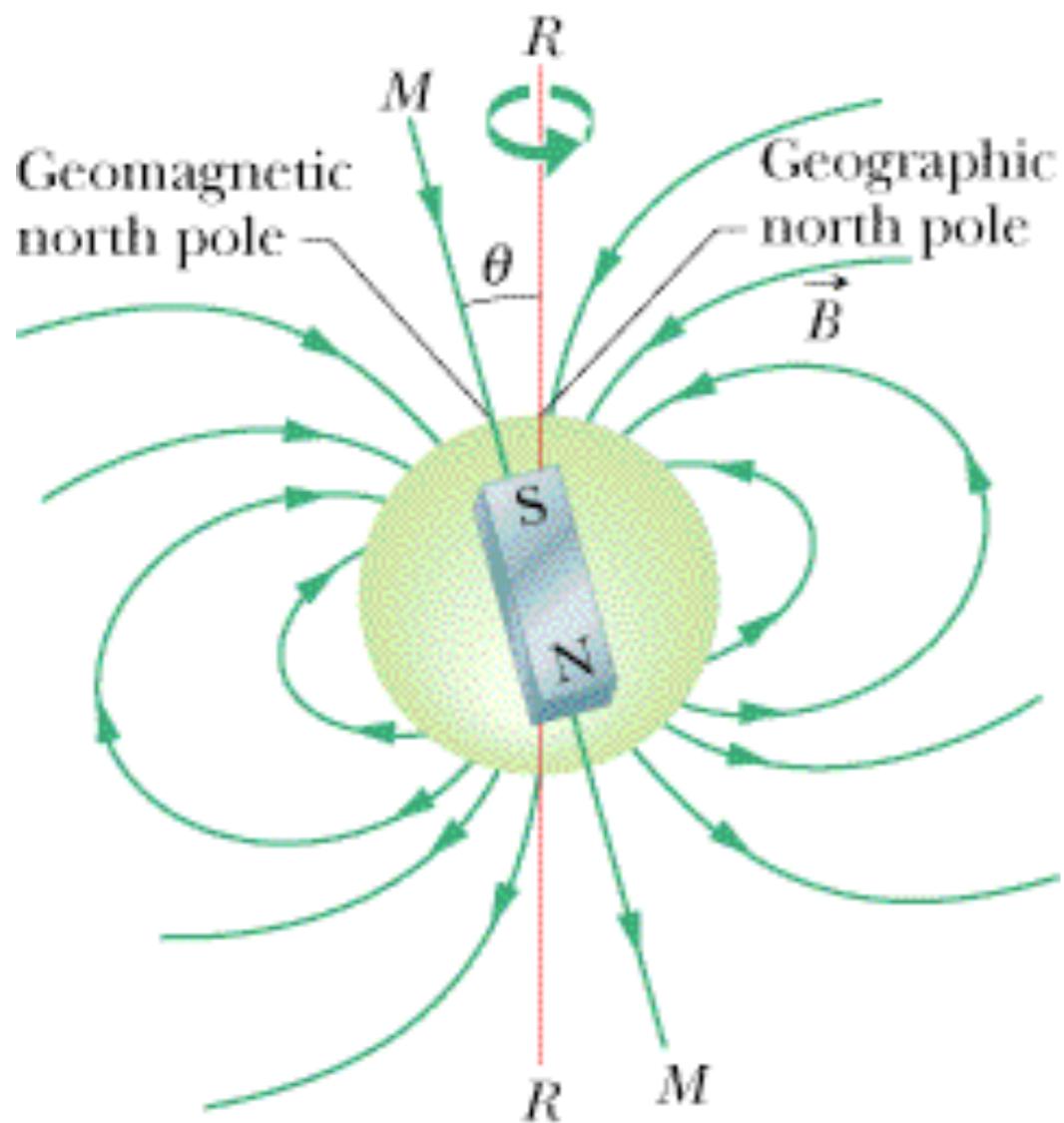
BOLD FMRI

Anatomy image
(TI)

Statistical image overlay:
color ~ P value

some physics preliminaries

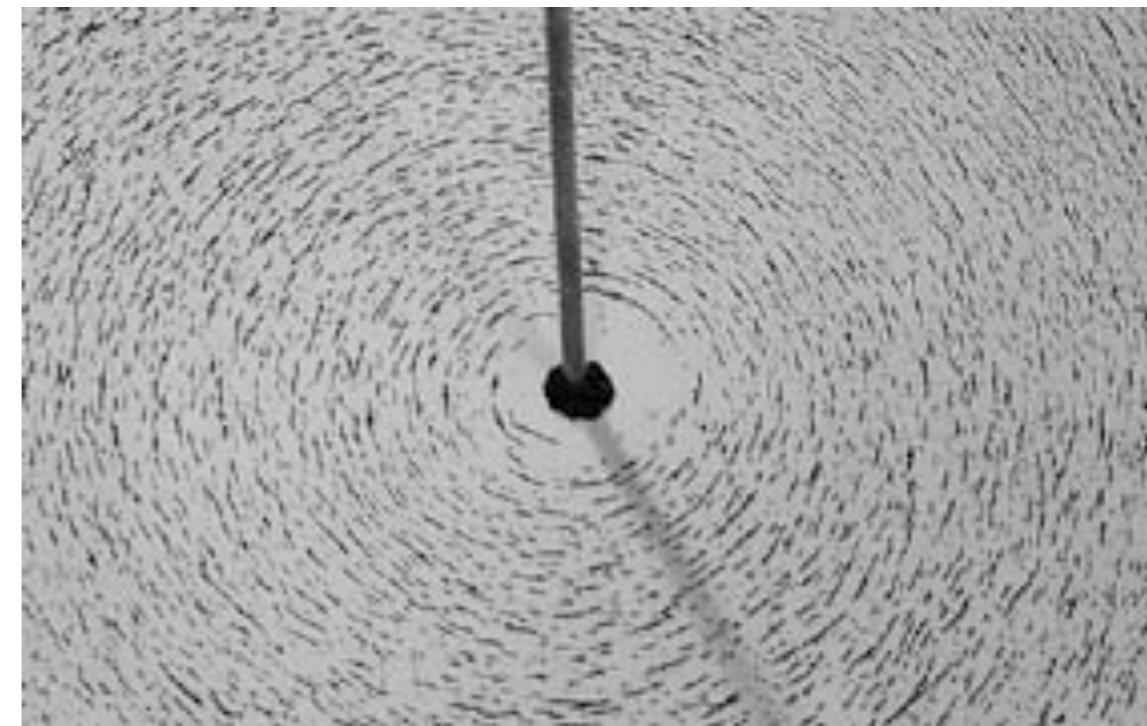
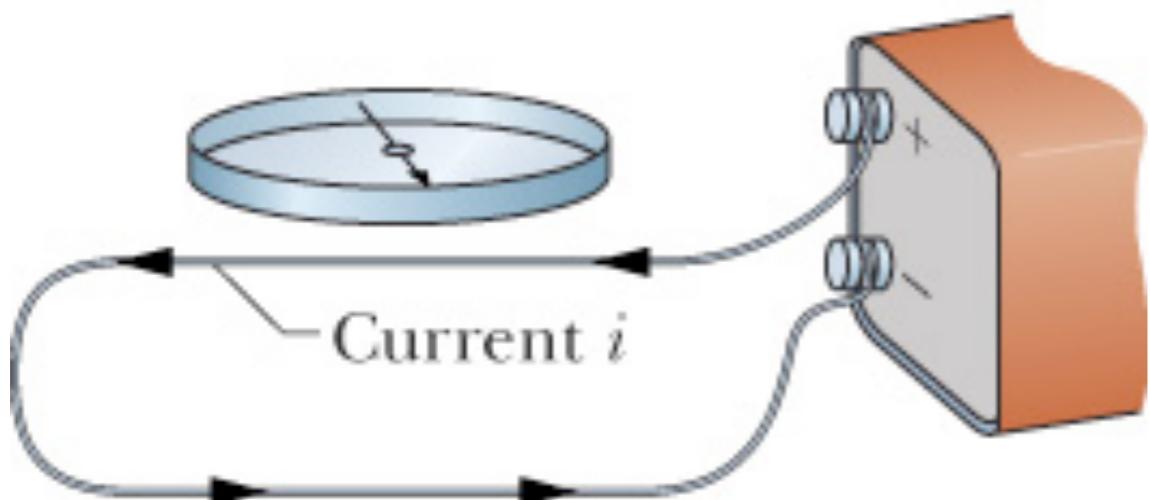
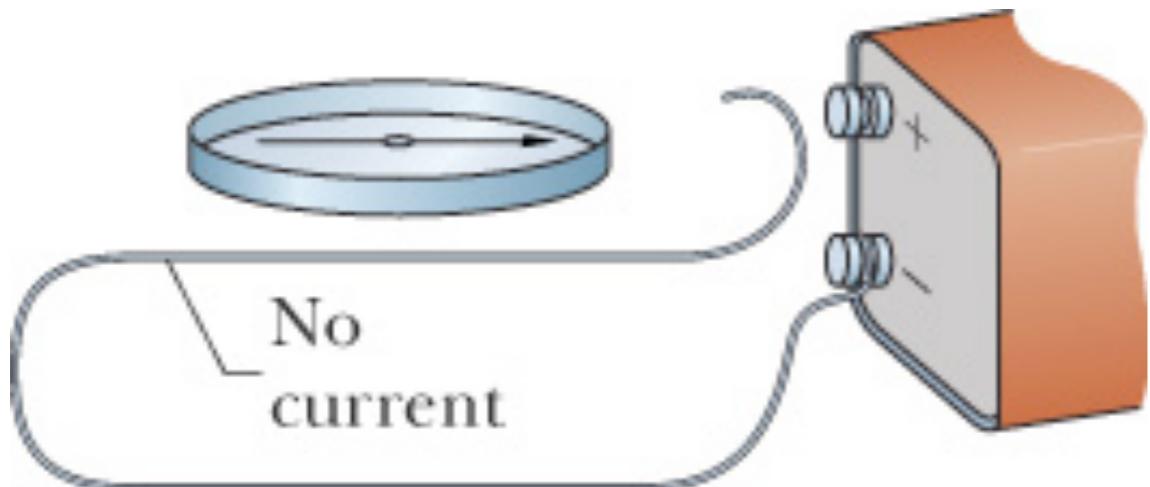
Magnets



Earth is a giant dipole with S pole near geographic N

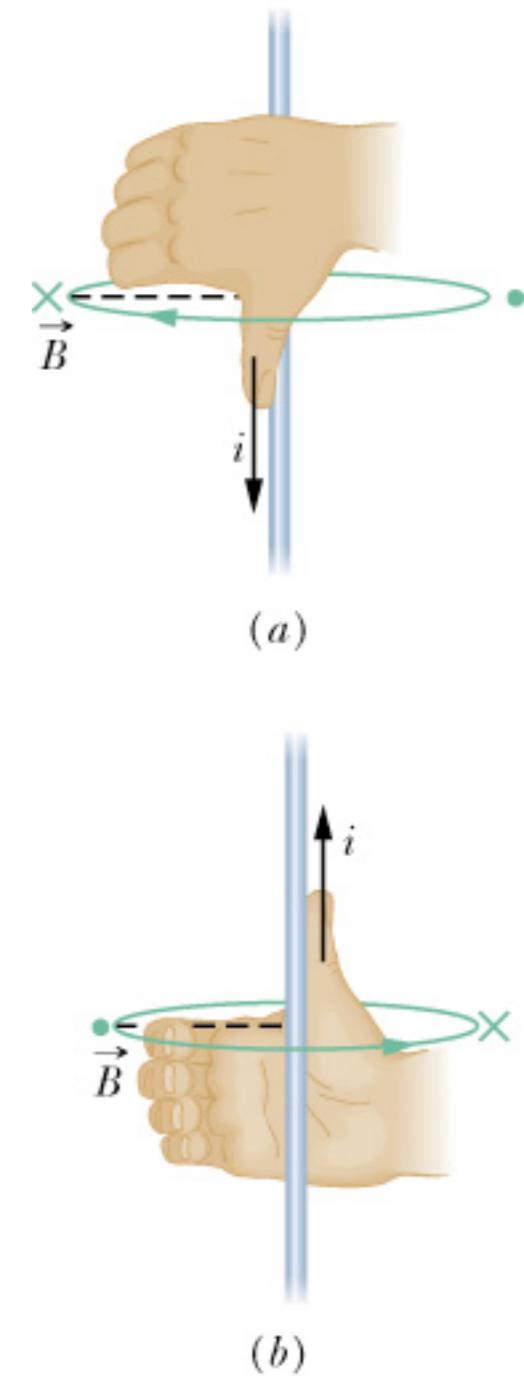
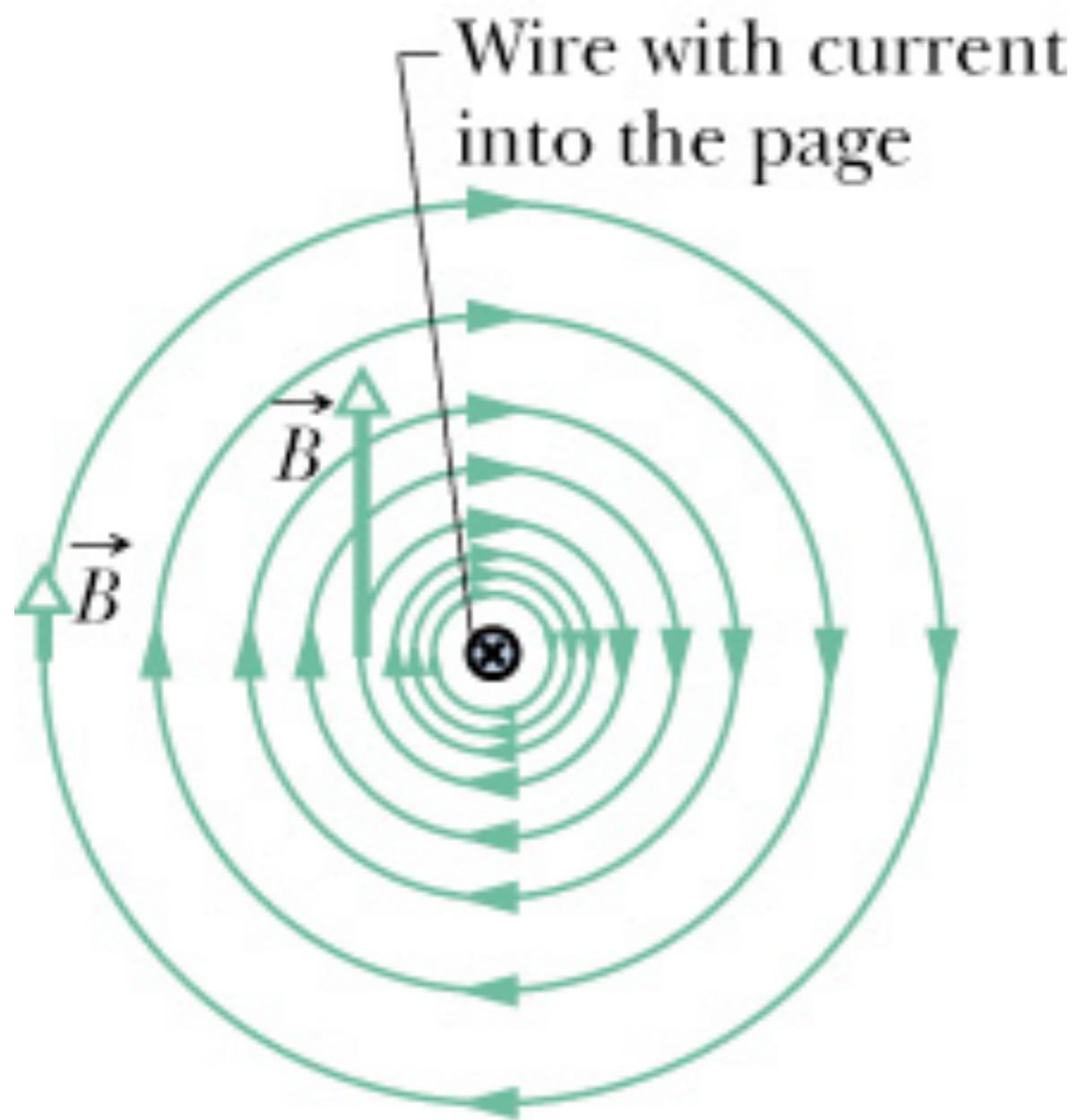
Current Produces Magnetic Field

Oersted 1820



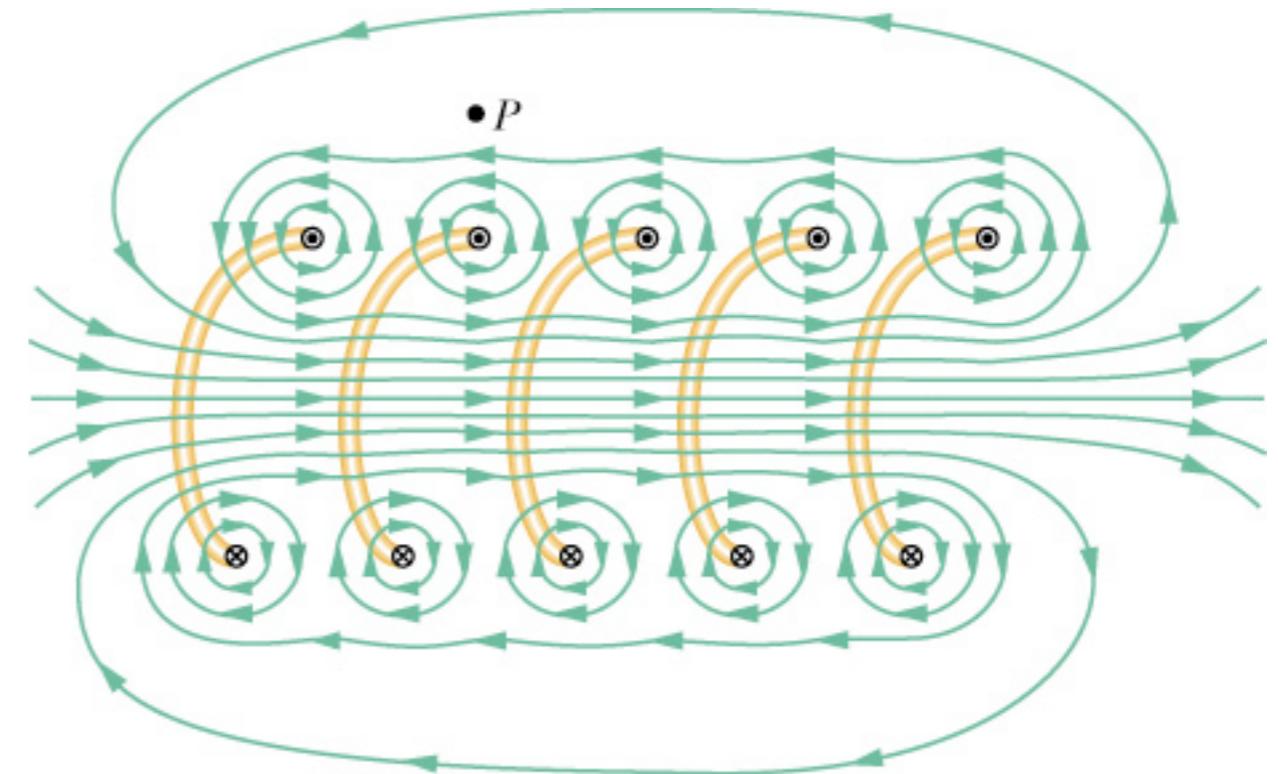
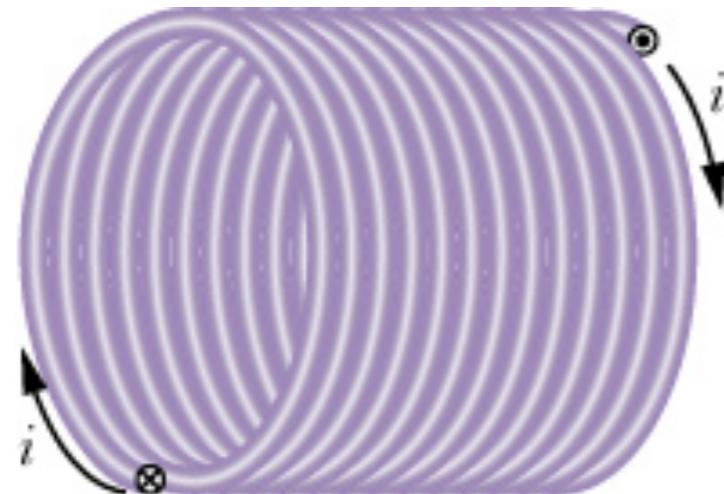
wire along earth
N-S axis

Field Due to a Straight Wire

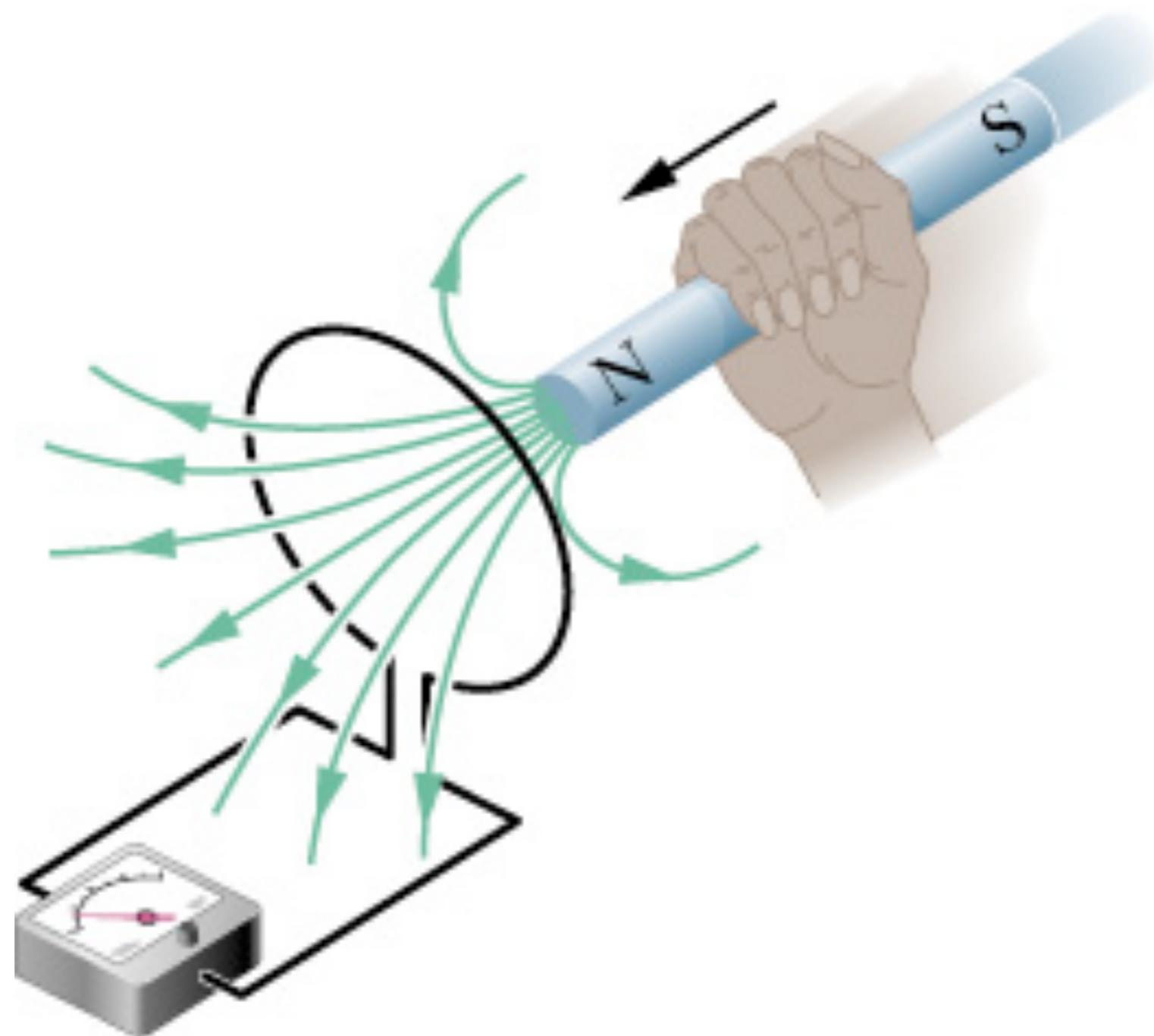


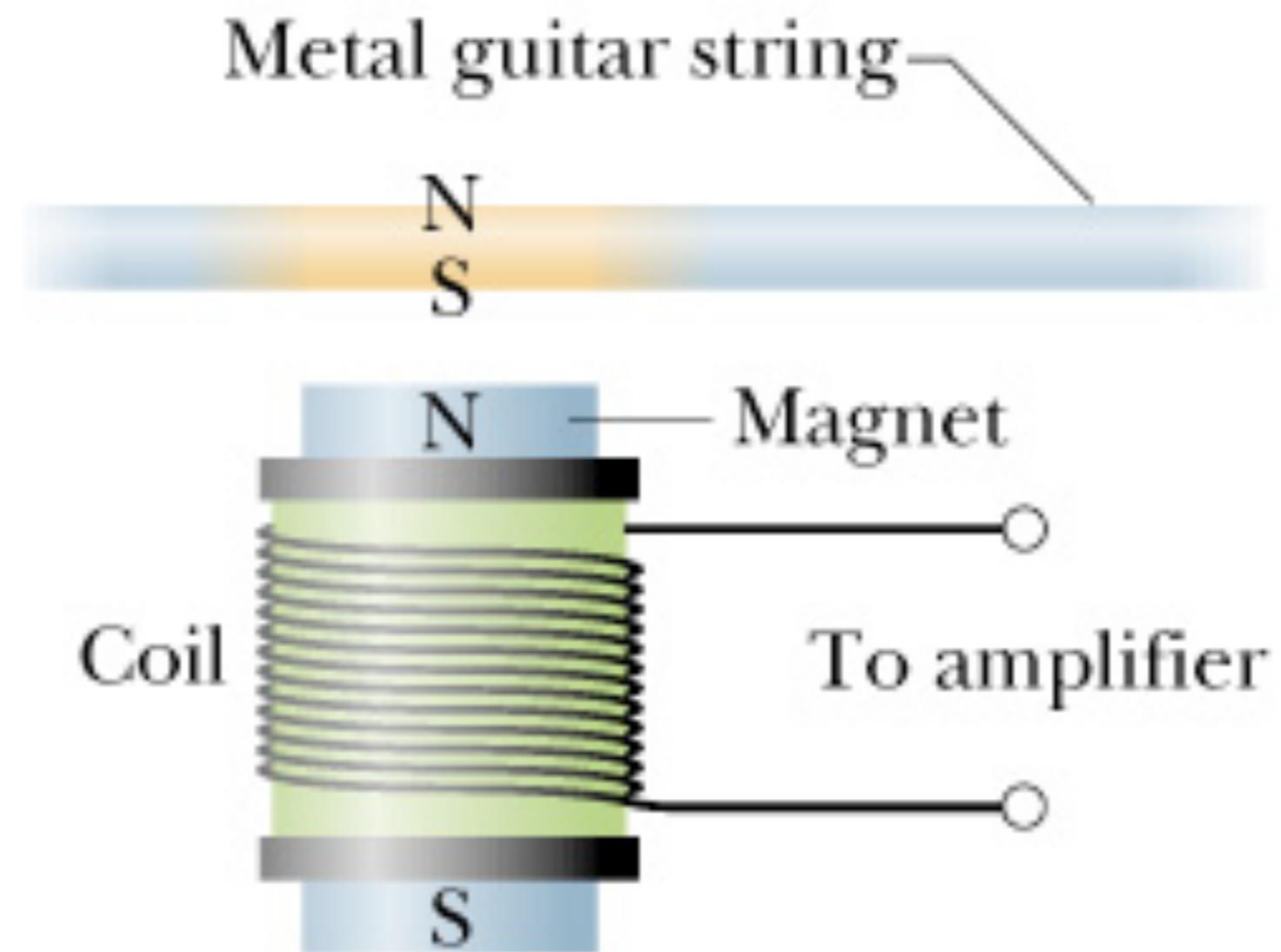
The Solenoid

Like the main magnet in an MRI machine

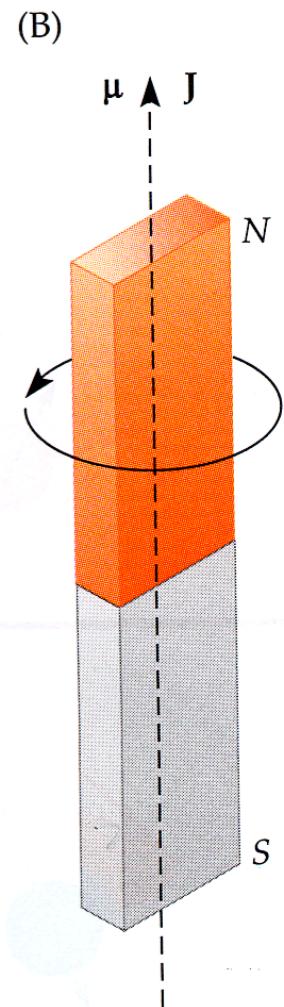
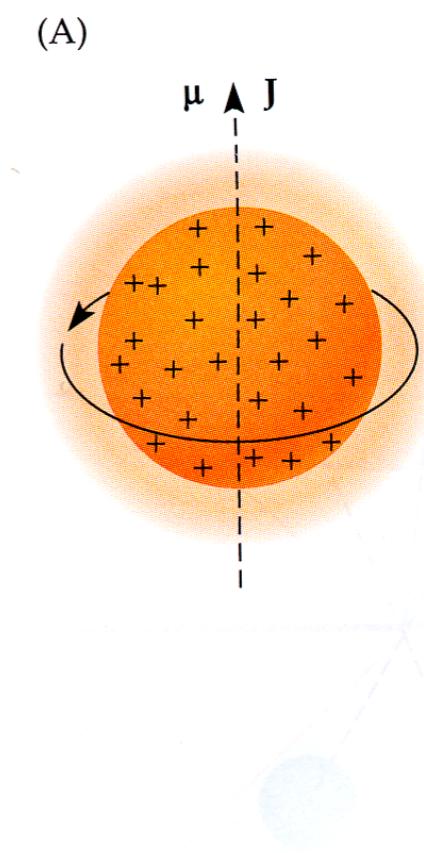
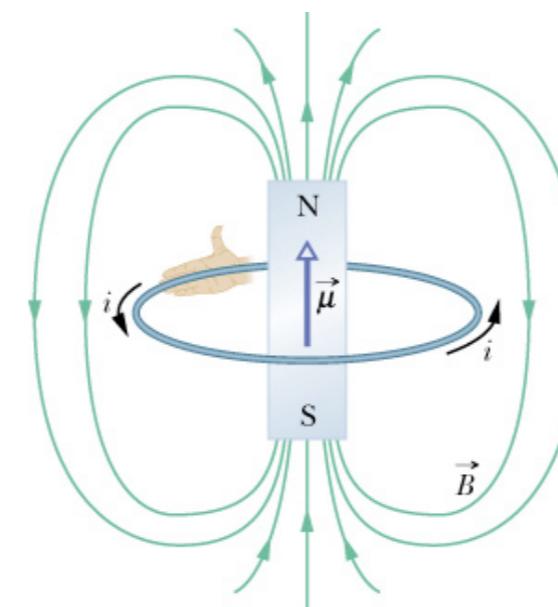
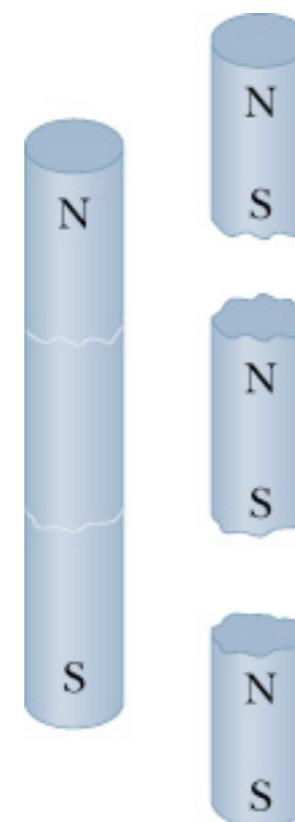


Induction





Microscopic magnets

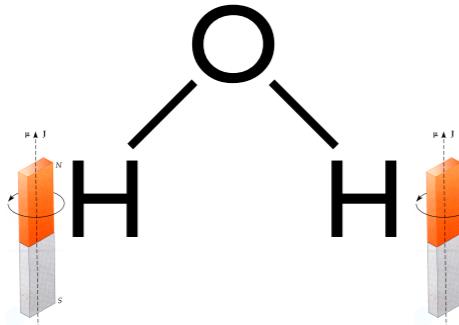


e⁻ and p⁺ have angular momentum (spin)
Electrons also have orbital angular momentum
Both of these result in magnetic dipole moments
No magnetic monopoles!

nuclear spins and magnetic resonance

Nuclear Spin

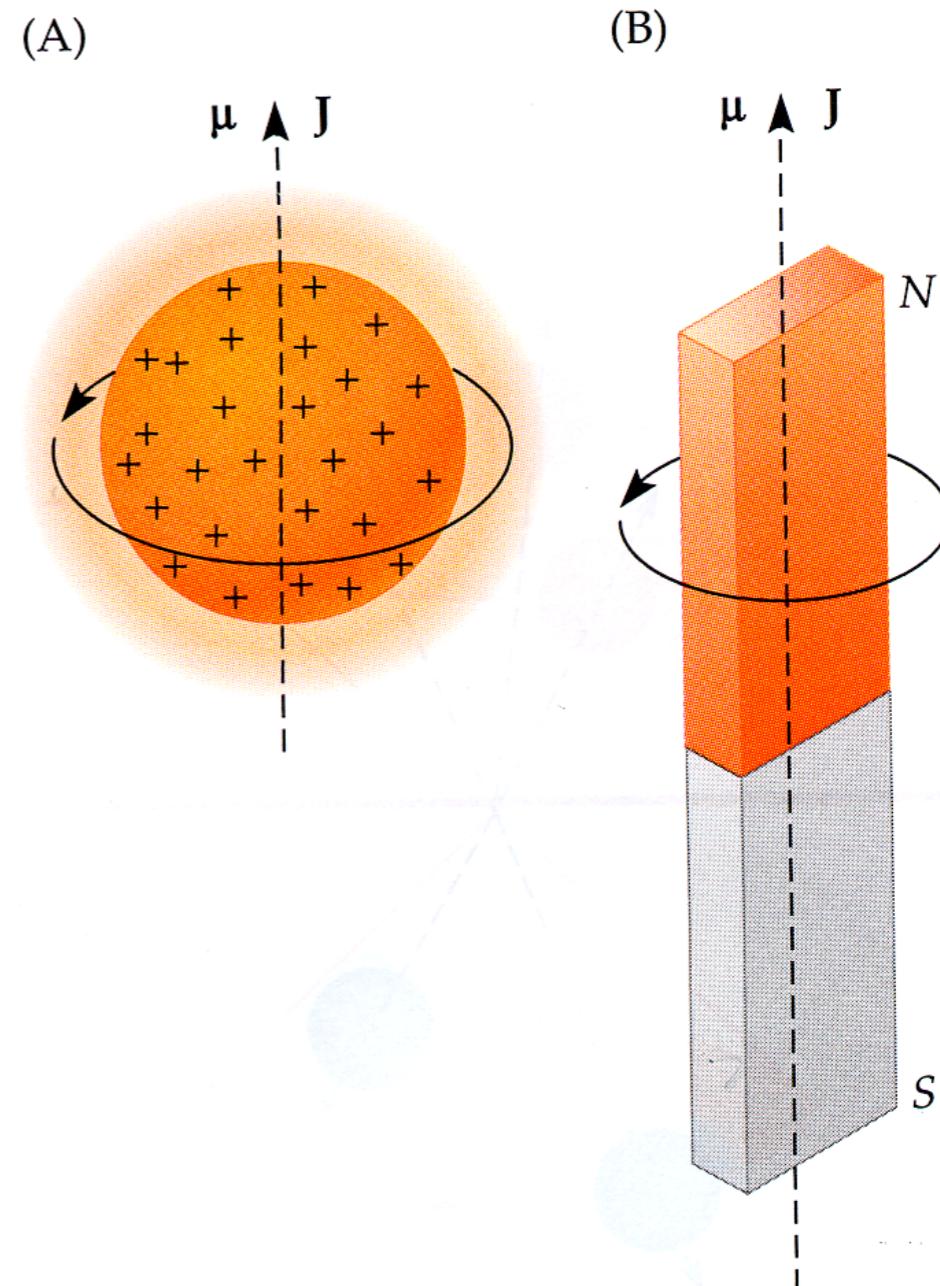
Water: H₂O



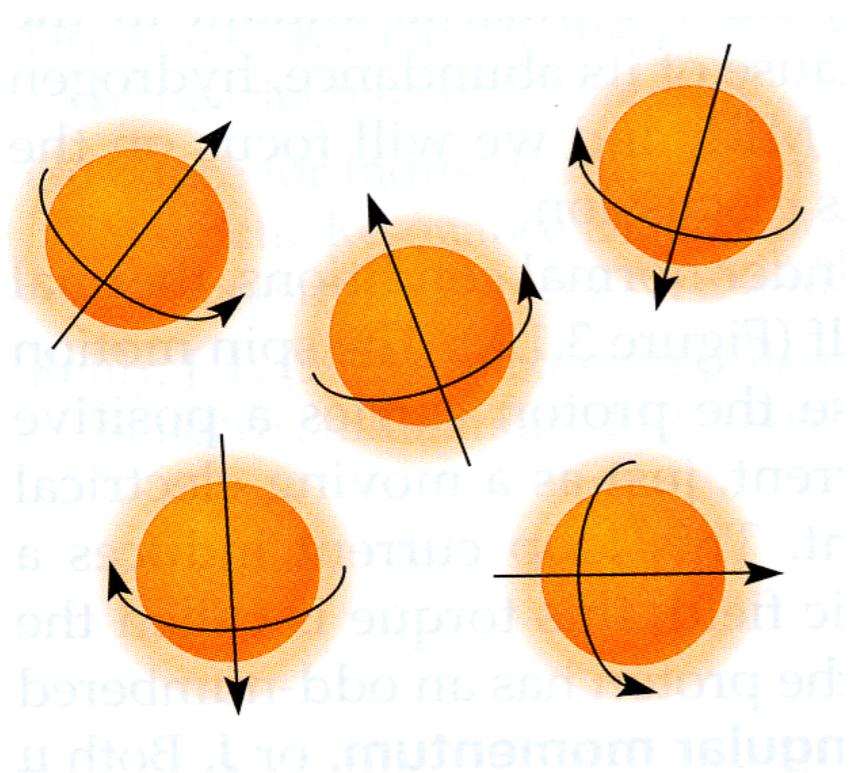
Protons have spin

- angular momentum (J)
- magnetic moment (μ)

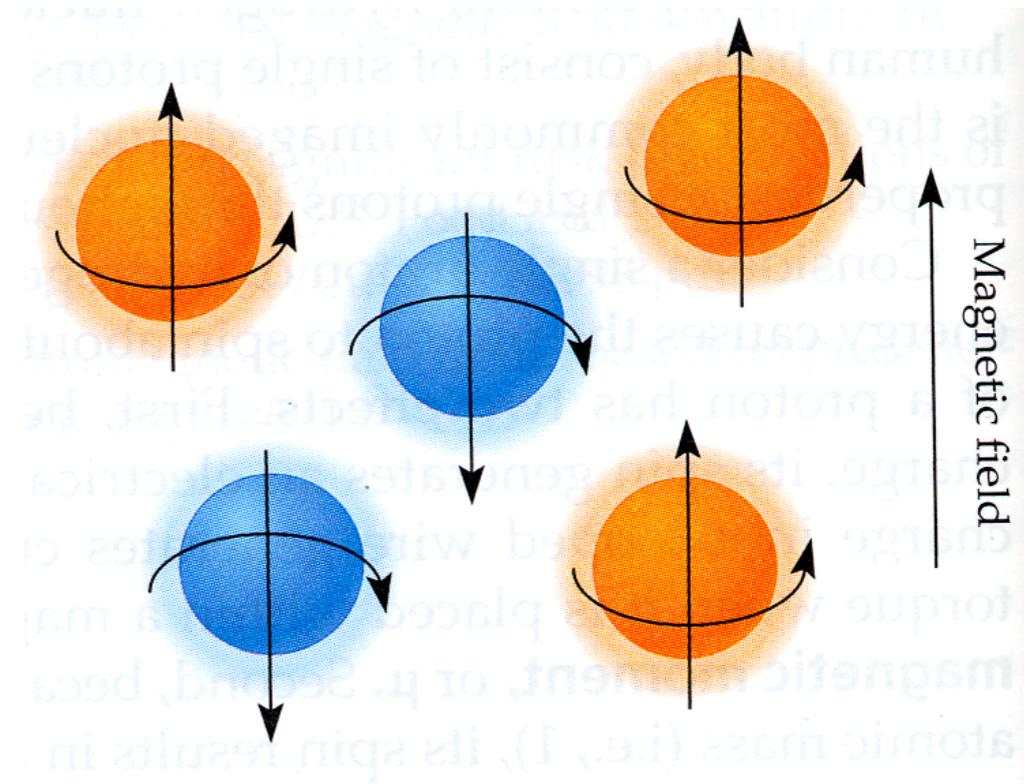
Look like small spinning bar magnets



Spins in Magnetic Field

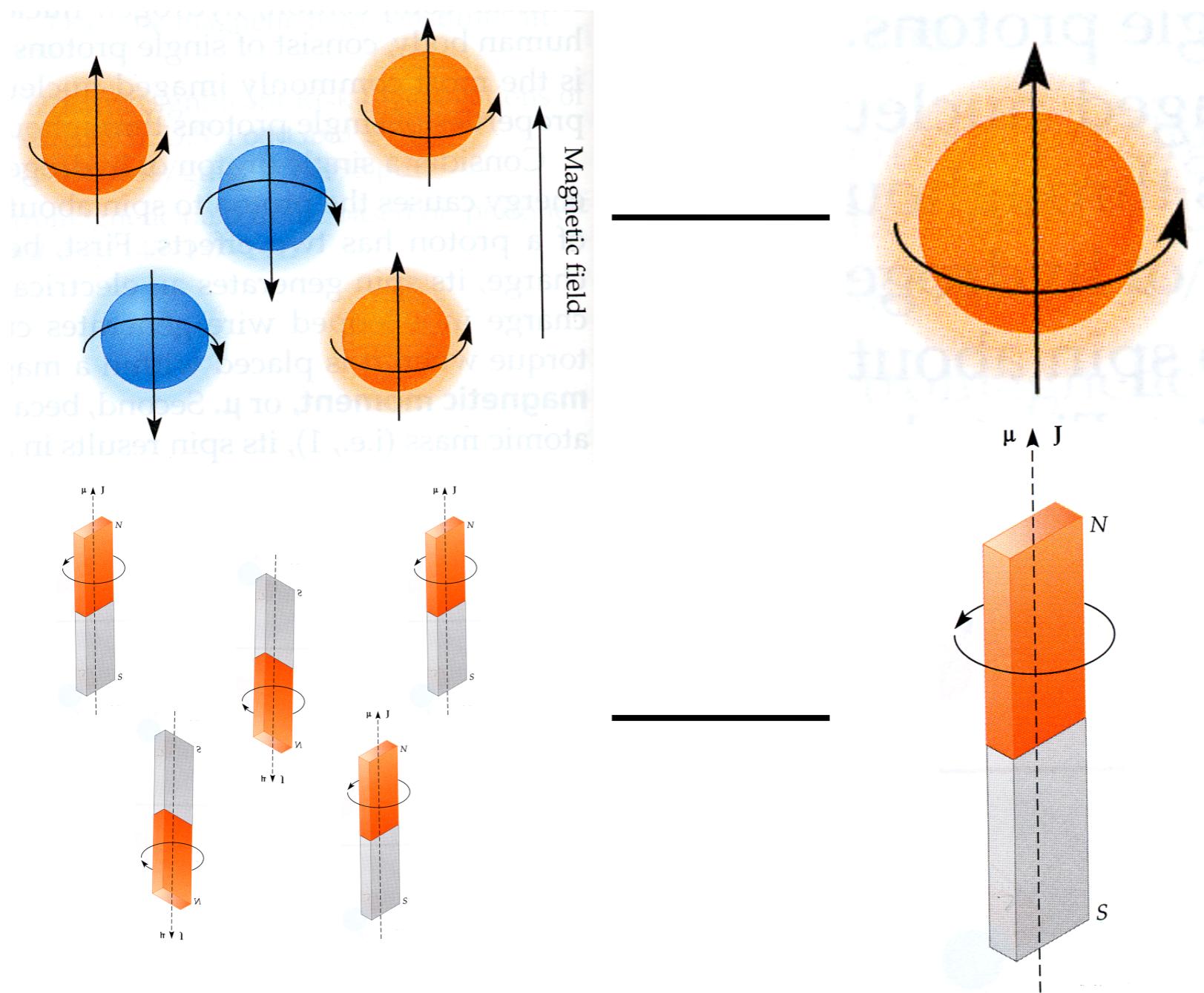


Magnetic Field = 0
Random orientation
One state

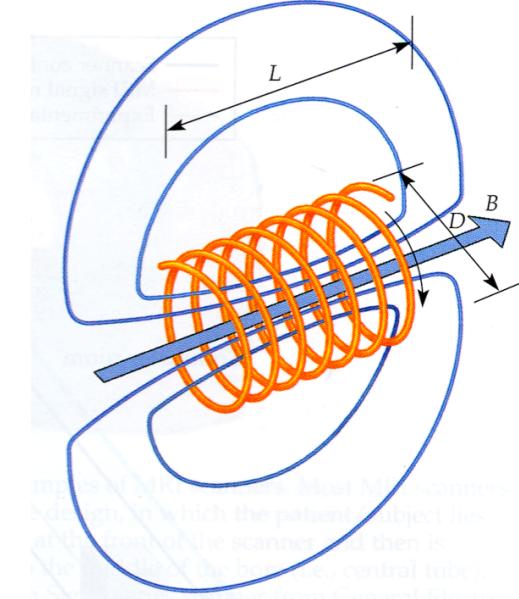


Magnetic Field $\neq 0$
Alignment. Two states
orange: parallel, low energy
blue: anti, high energy

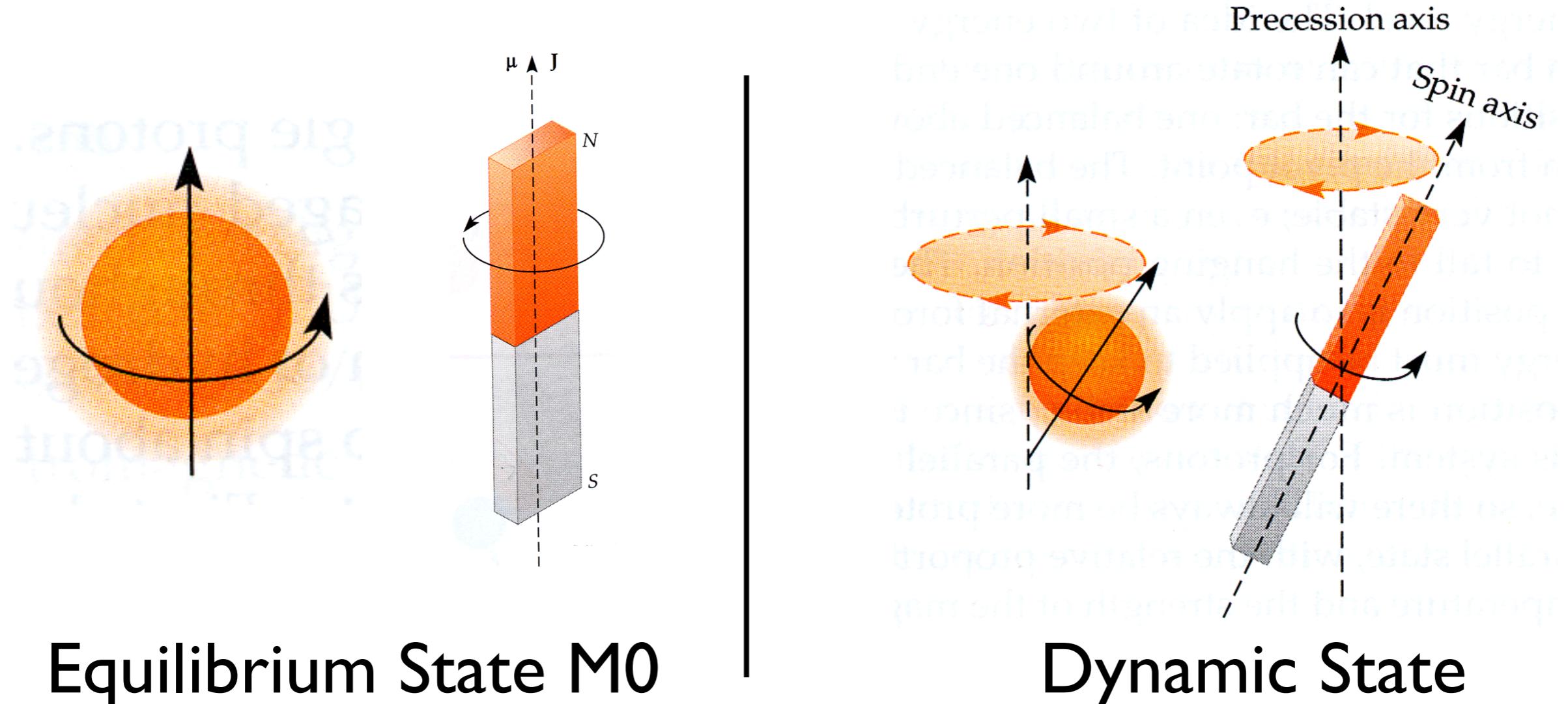
Many Spins: Net Magnetization



Main Field B_0



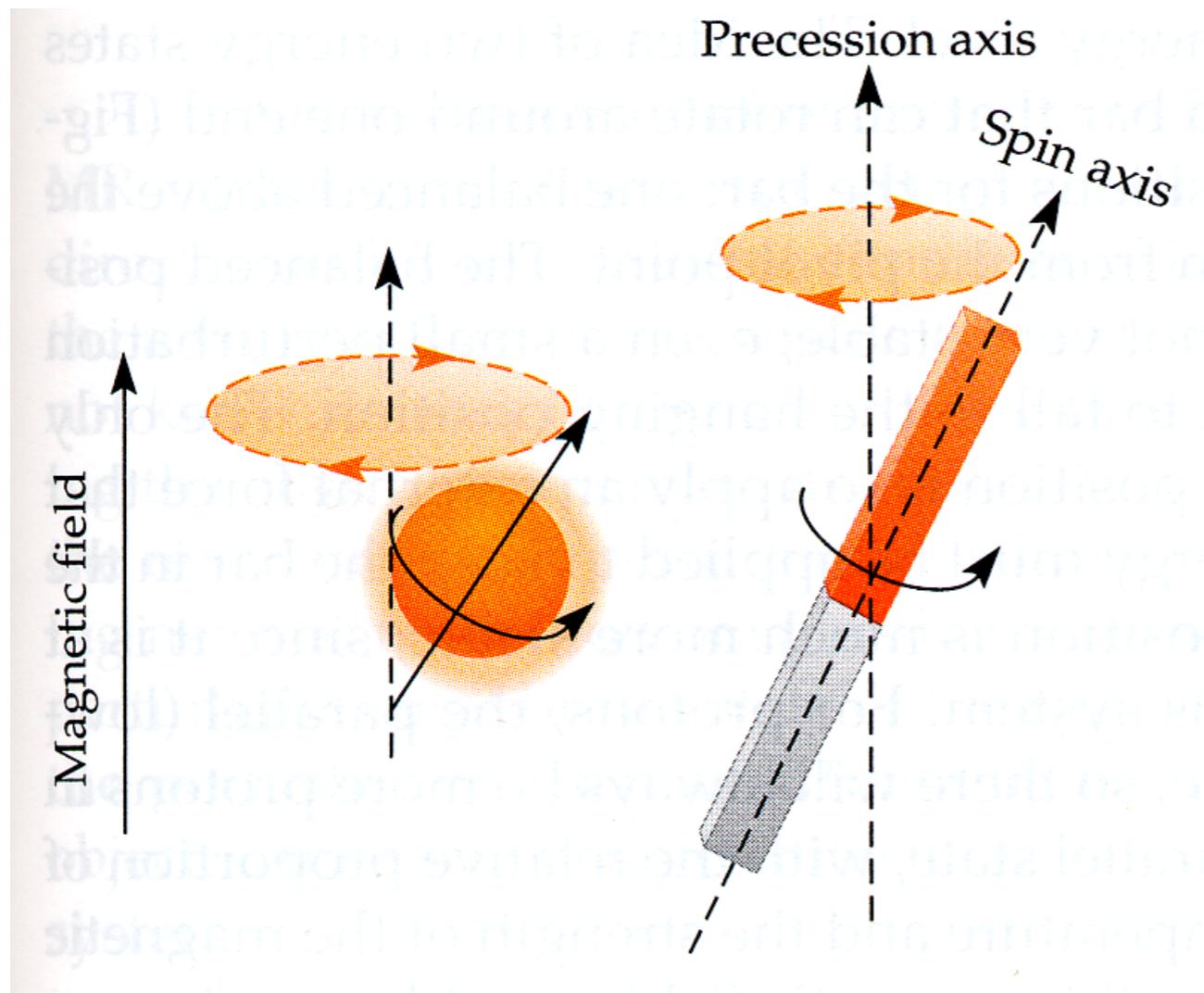
The Magnetization Vector



M_0 proportional to number of spins
and strength of magnetic field.

$$M_0 \sim N B_0$$

Precession of Spins



$$\omega = \gamma B$$

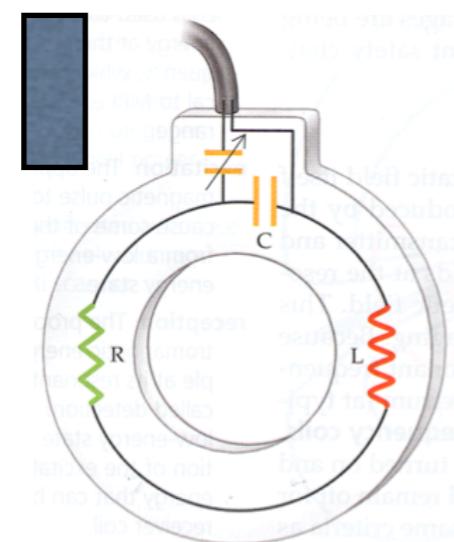
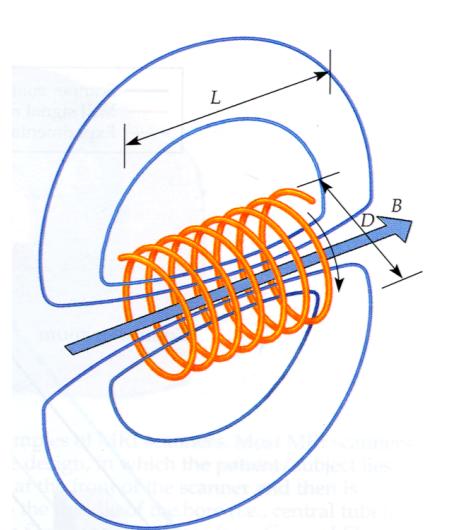
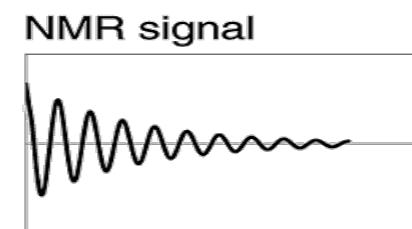
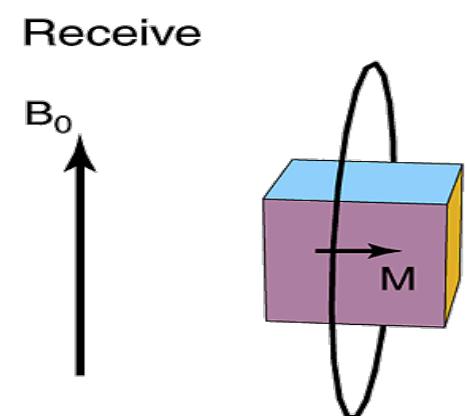
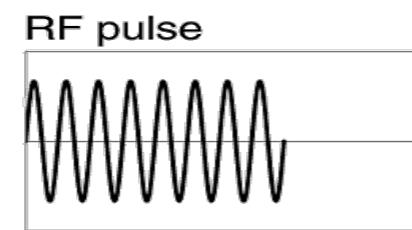
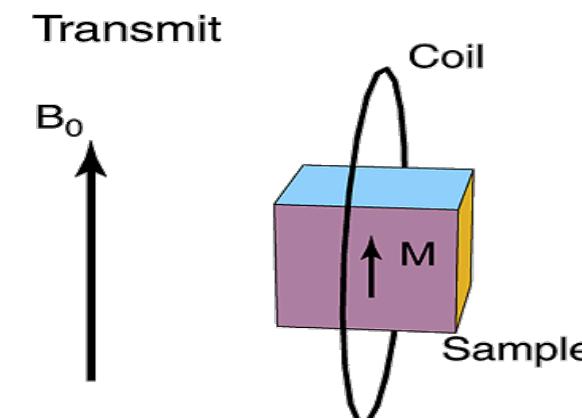
	1.5	3T	7T
1H	64	128	300
13C	16	32	75

Larmor Equation:
Precession frequency proportional
to magnetic field strength

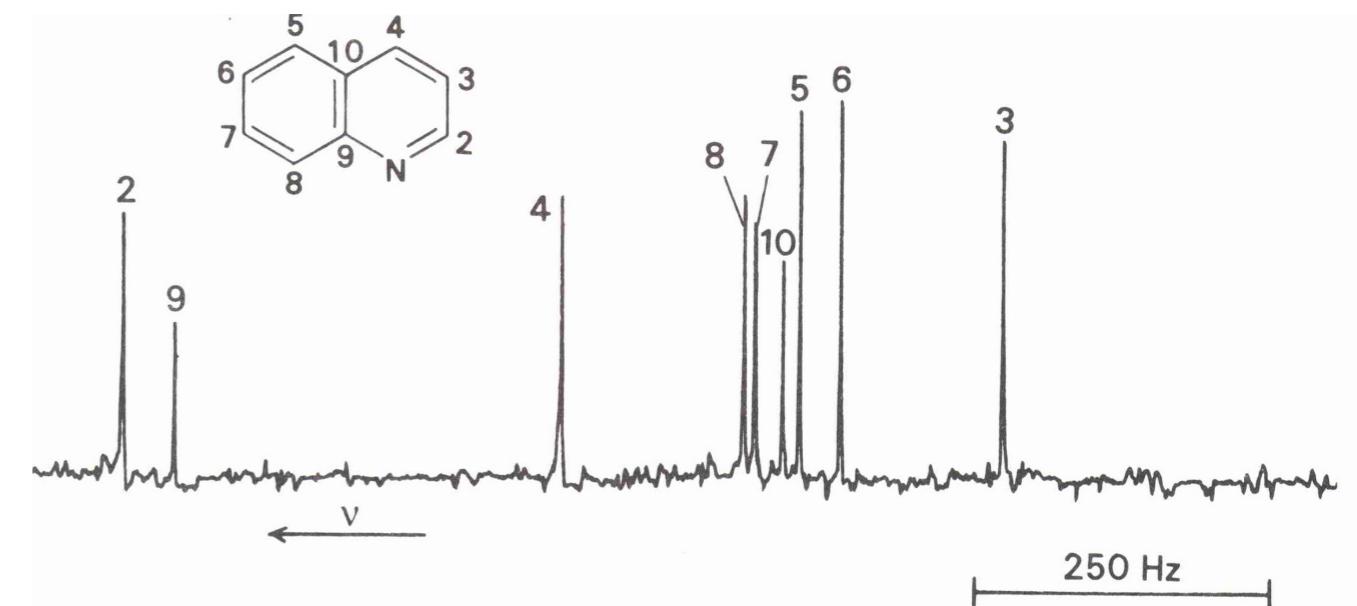
(MHz)

the NMR experiment

The NMR Experiment

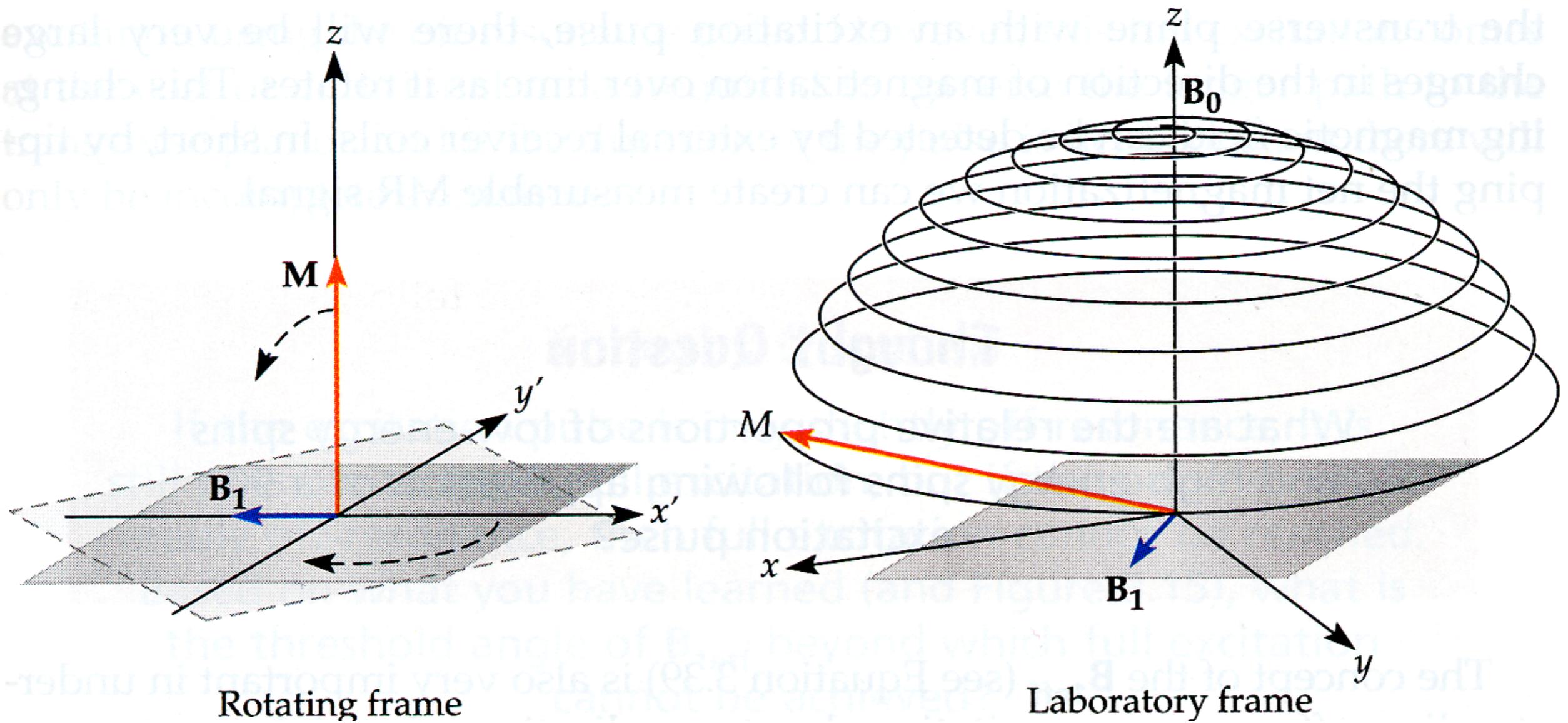


tuned circuit



- 0) Put sample in magnet
- I) Push magnetization into transverse plane
- 2) Detect NMR signal
- 3) Produce power spectrum

Push the Magnetization

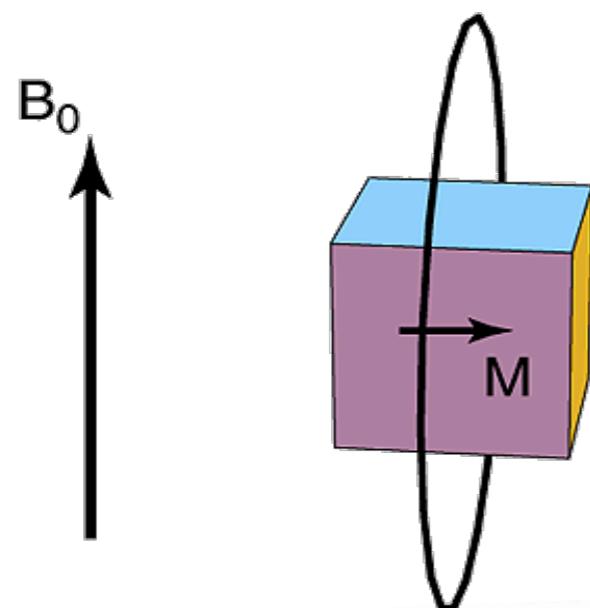


RF pulse frequency must match rotation frequency of \mathbf{M} (resonance)

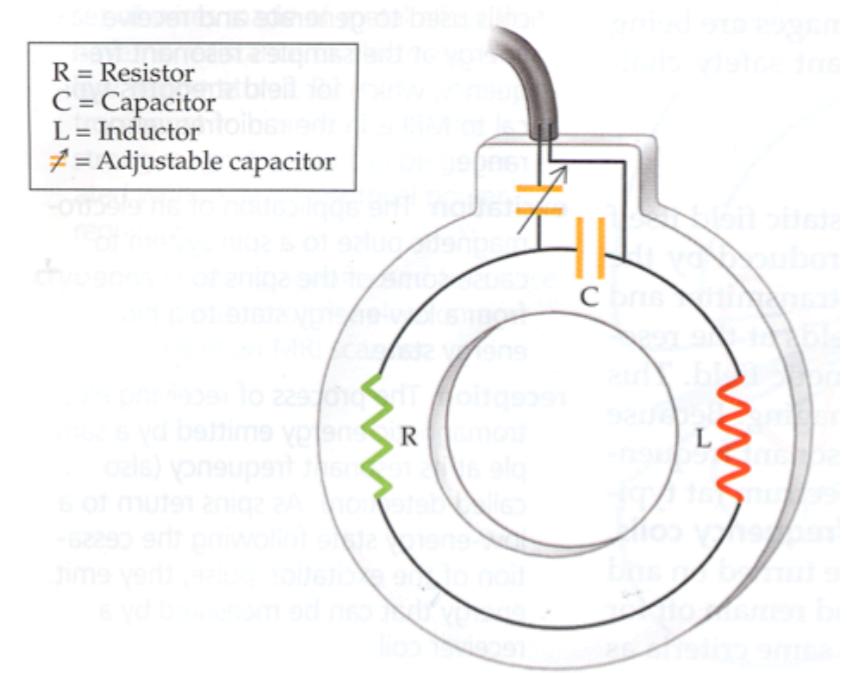
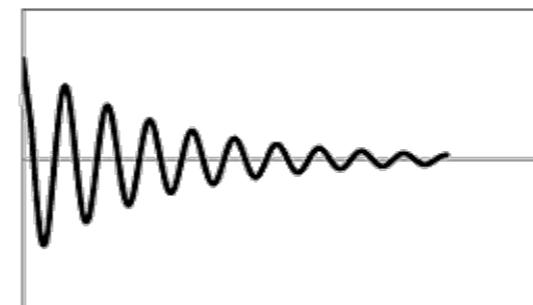
RF pulse amplitude and duration control flip angle

Detect Transverse Magnetization

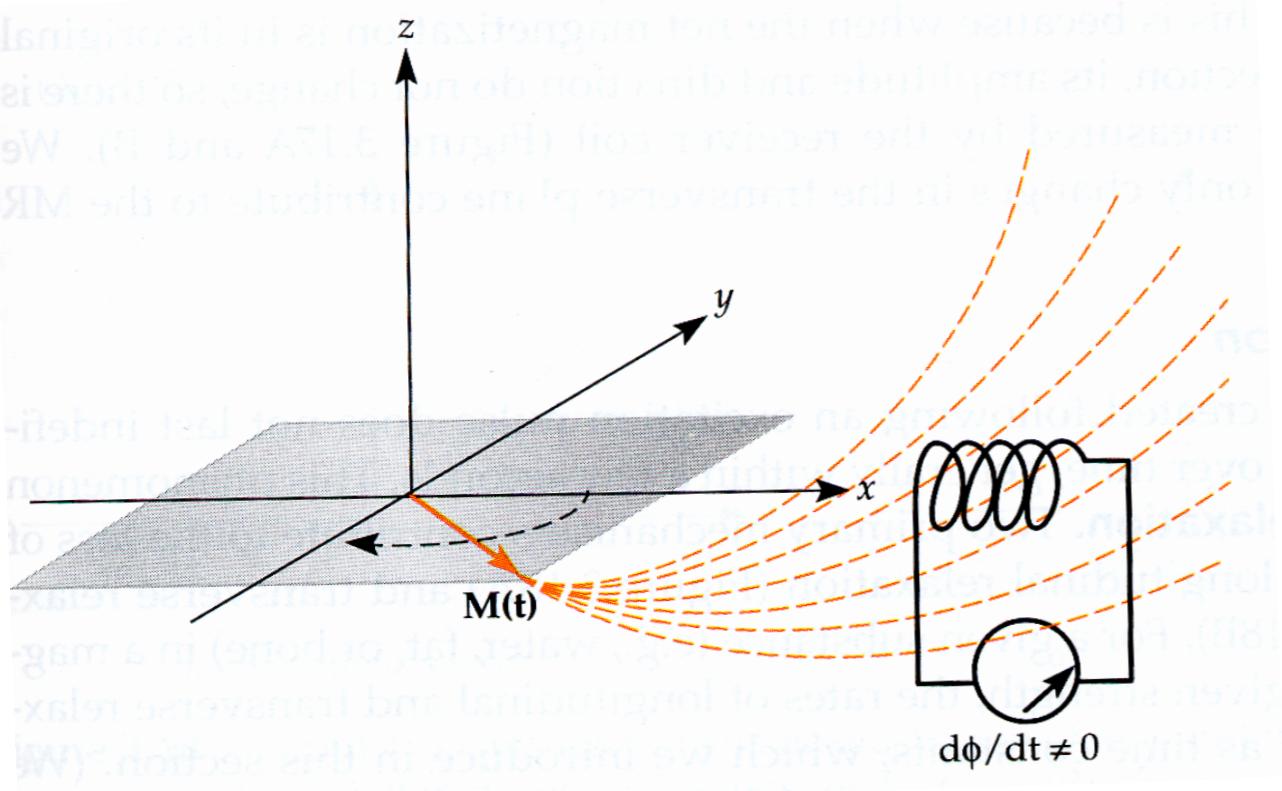
Receive



NMR signal

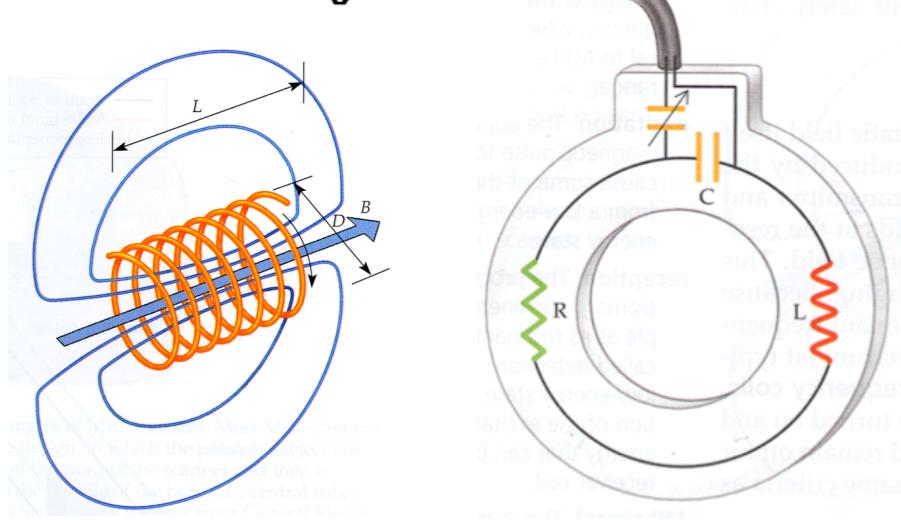
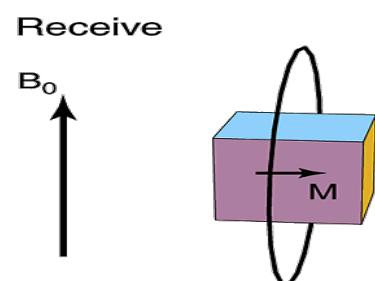
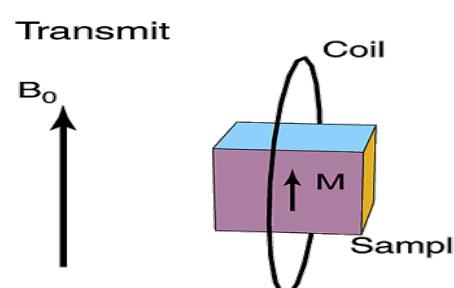
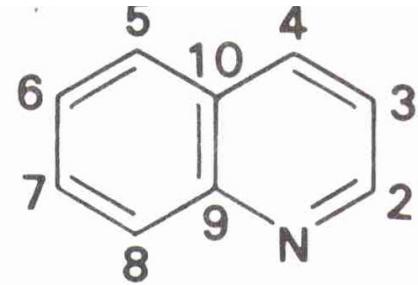


$$S(t) = \int_x \int_y \int_z M_{xy}(x, y, z, t) dx dy dz$$



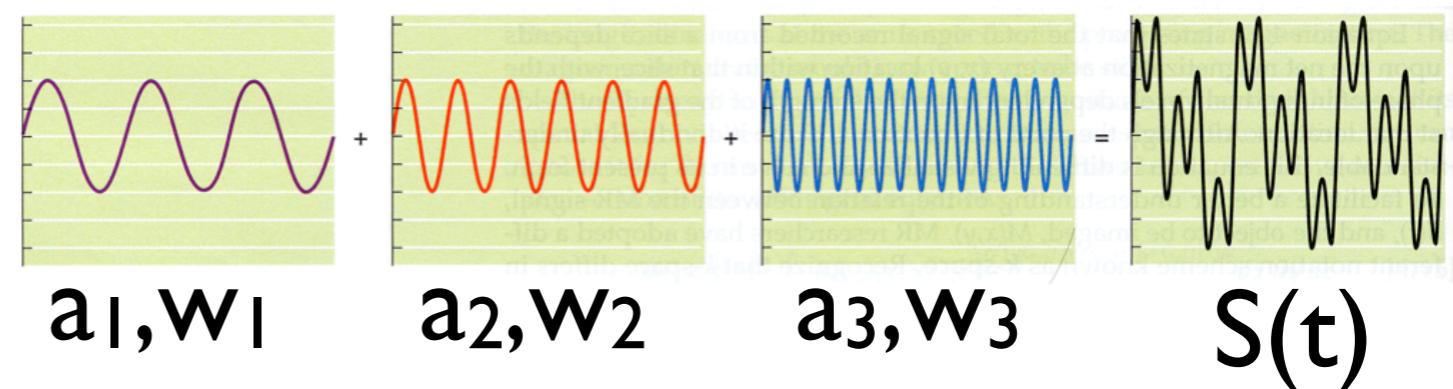
Coil integrates over space
Detect rotating transverse
magnetization by induction.

The NMR Experiment



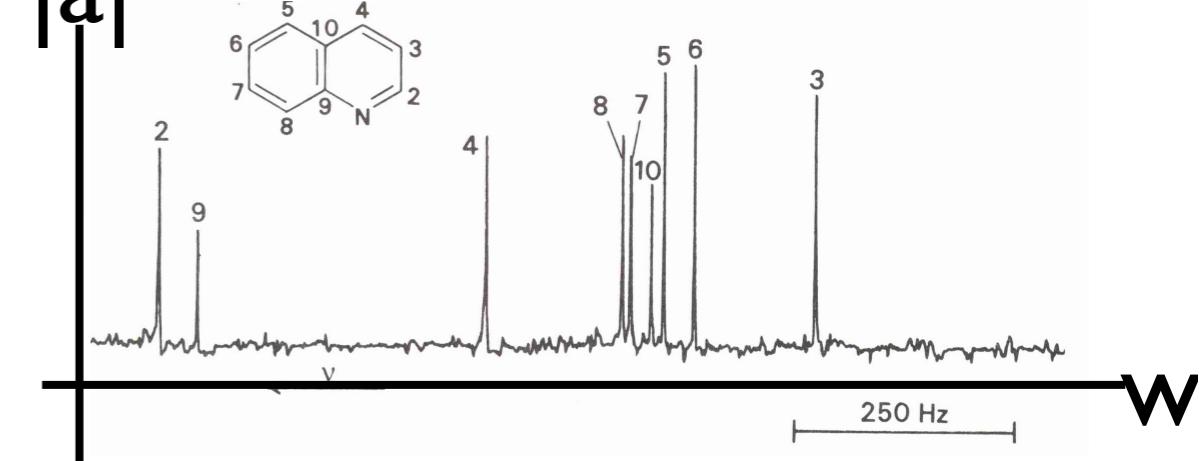
$$\omega_j = \gamma B_j$$

$$M_{xy,j}(t) = a_j e^{-t/T_2} e^{i\omega_j t} \approx a_j e^{i\omega_j t}$$



$$S(t) = a_1 e^{i\omega_1 t} + a_2 e^{i\omega_2 t} + a_3 e^{i\omega_3 t} + \dots$$

Fourier Transform
|a|



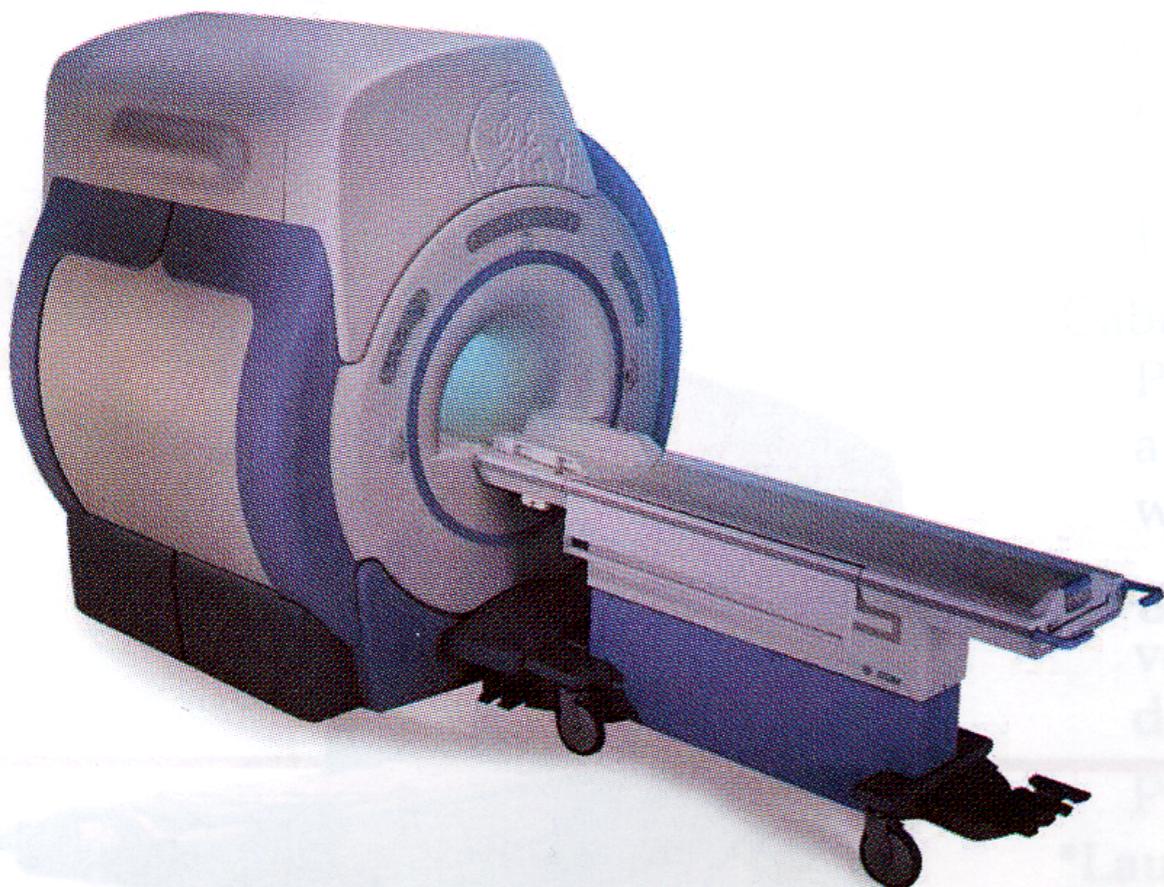
the MRI machine

i.e.

what is inside the donut

MRI Scanner Hardware

(A)



General Electric

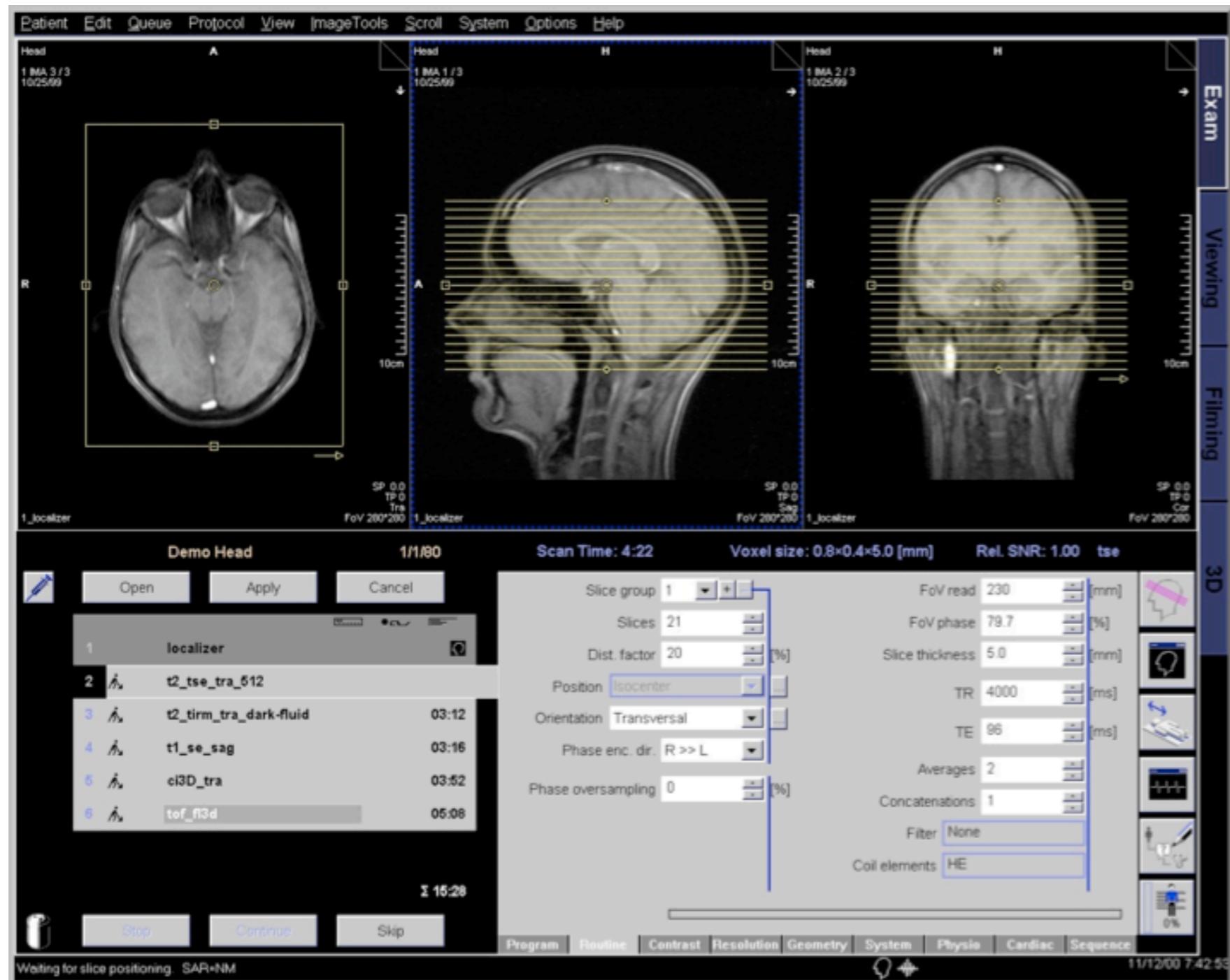
(B)



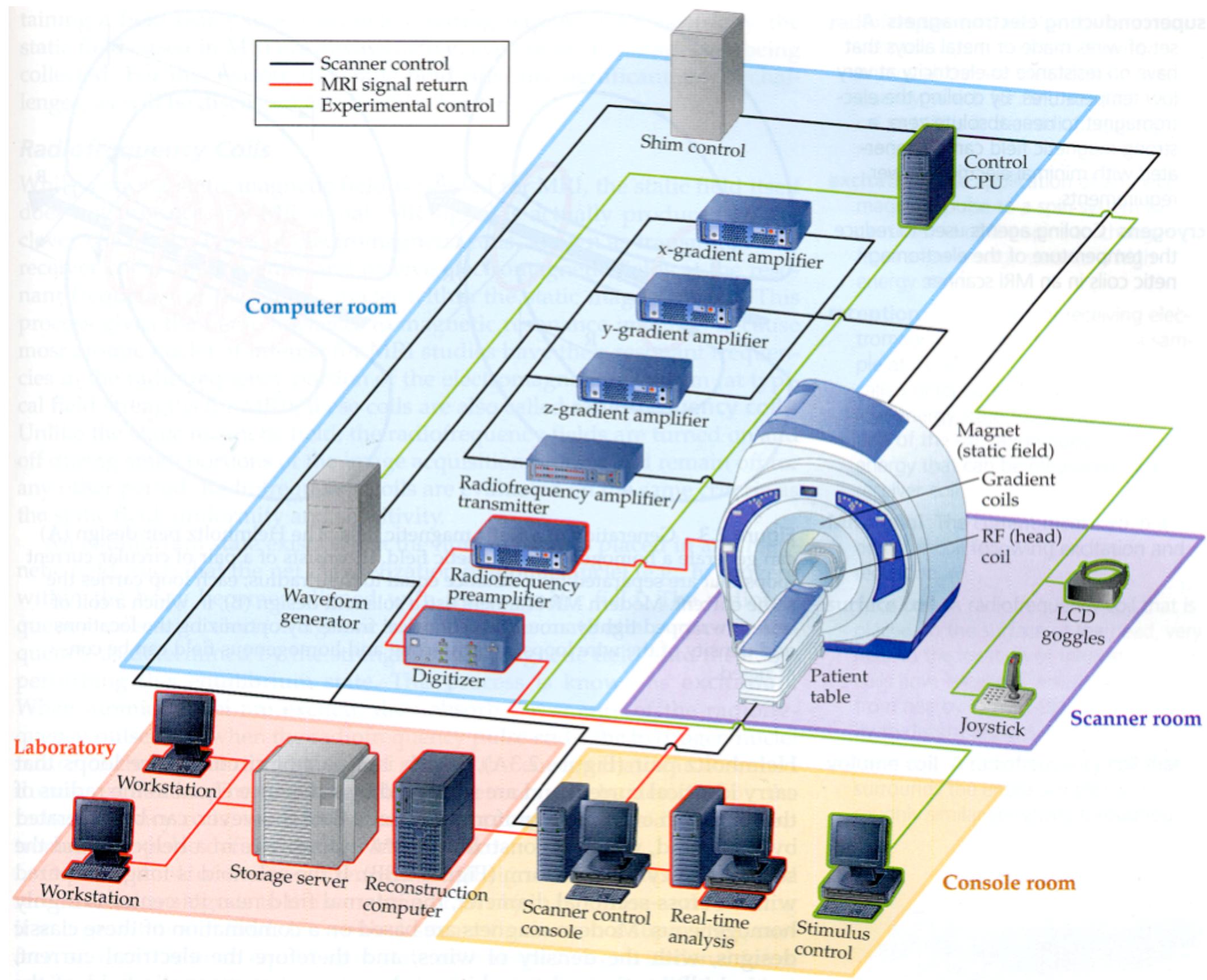
Siemens

Other big vendors: Phillips, Varian, Bruker

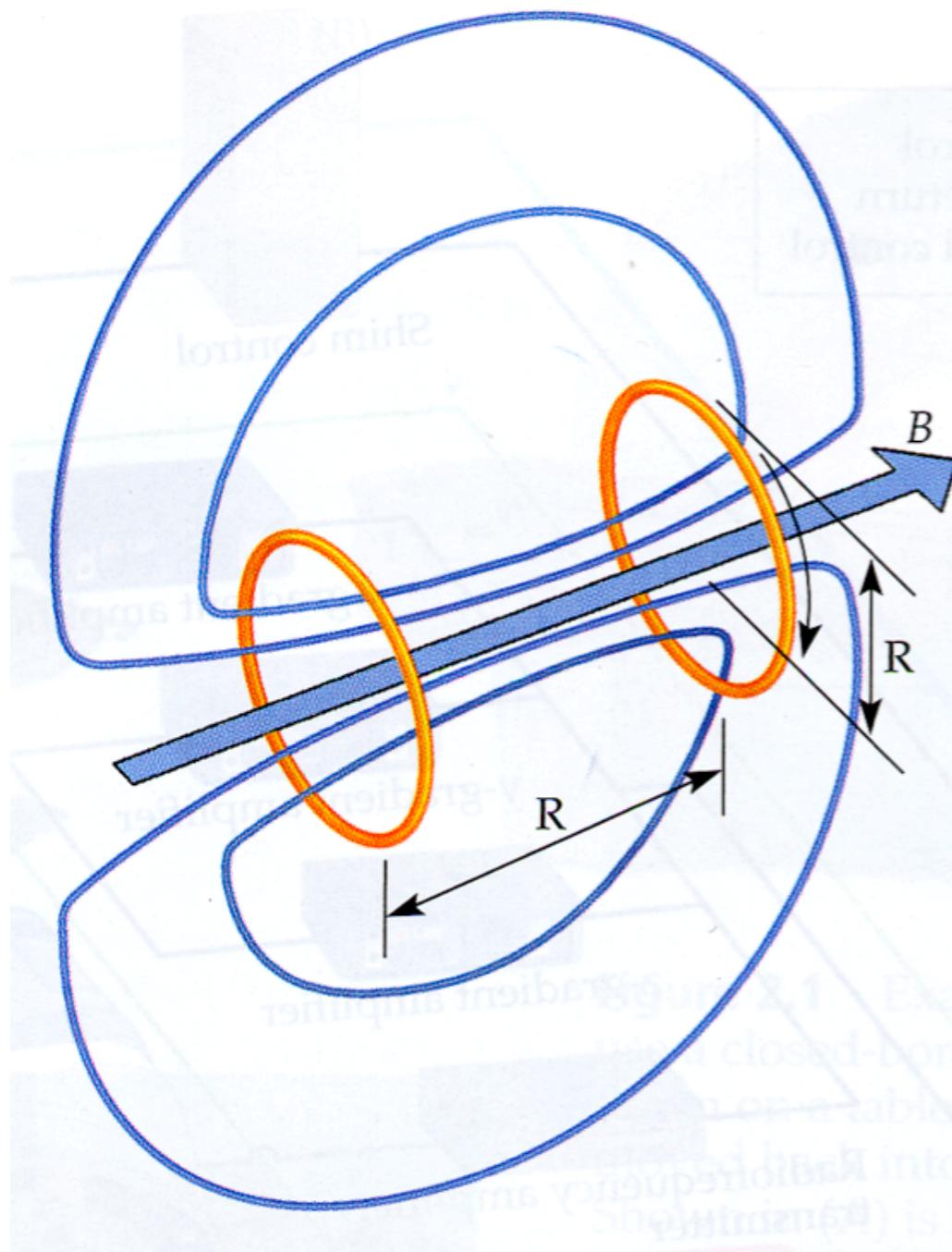
Scanner Console GUI



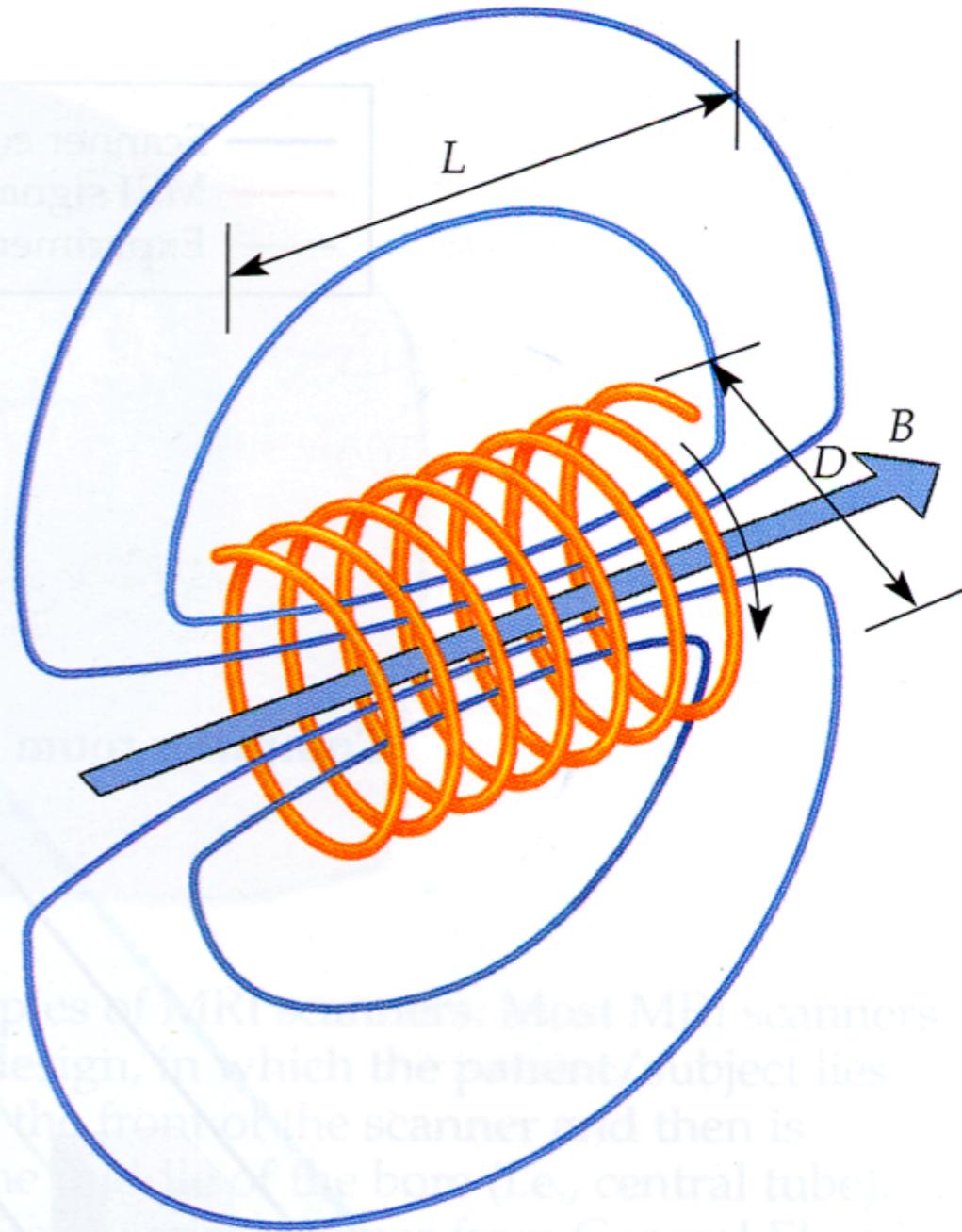
MRI Suite



Main Magnetic Field



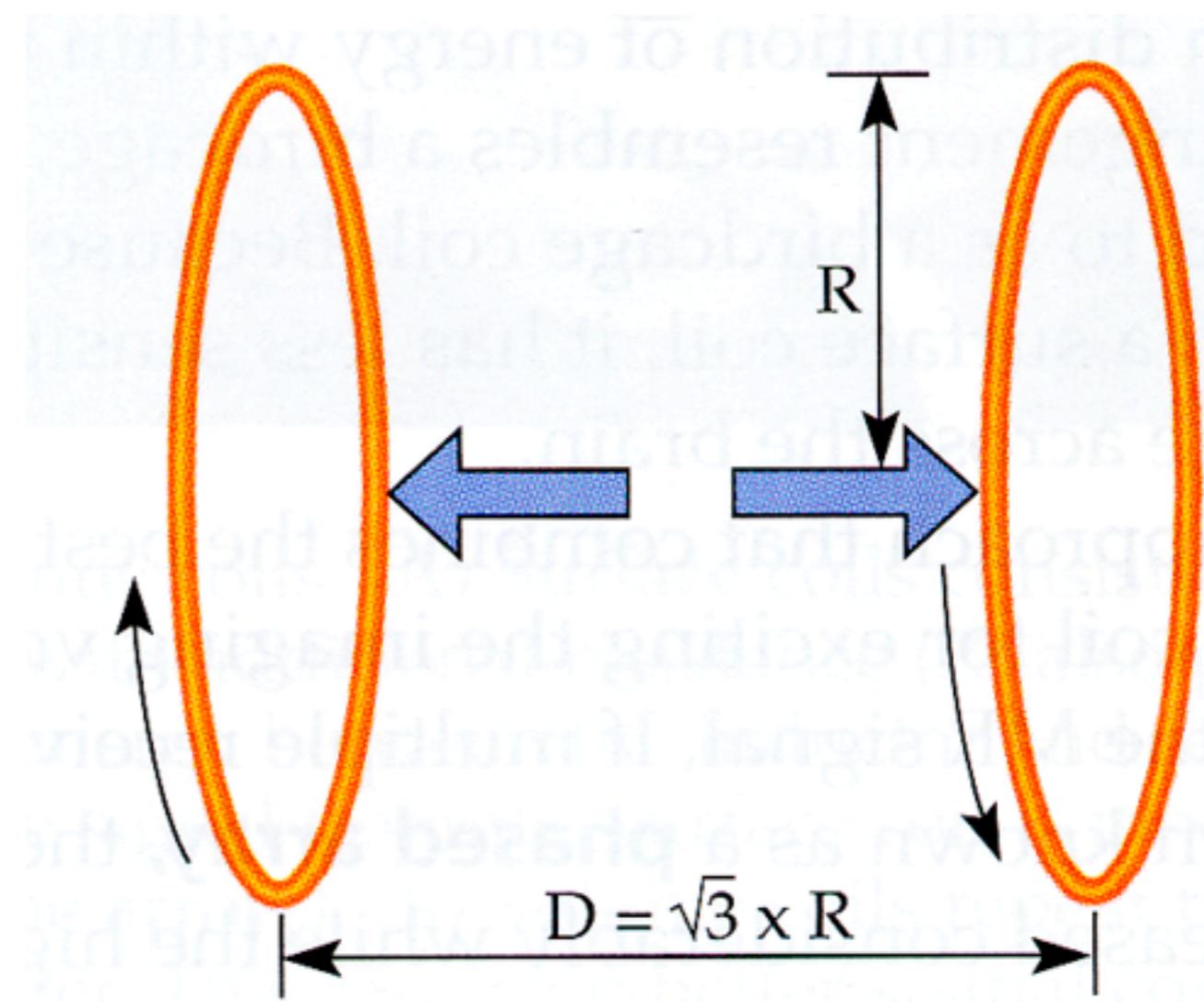
Helmholtz pair



Solenoid

Magnetic Field Gradient

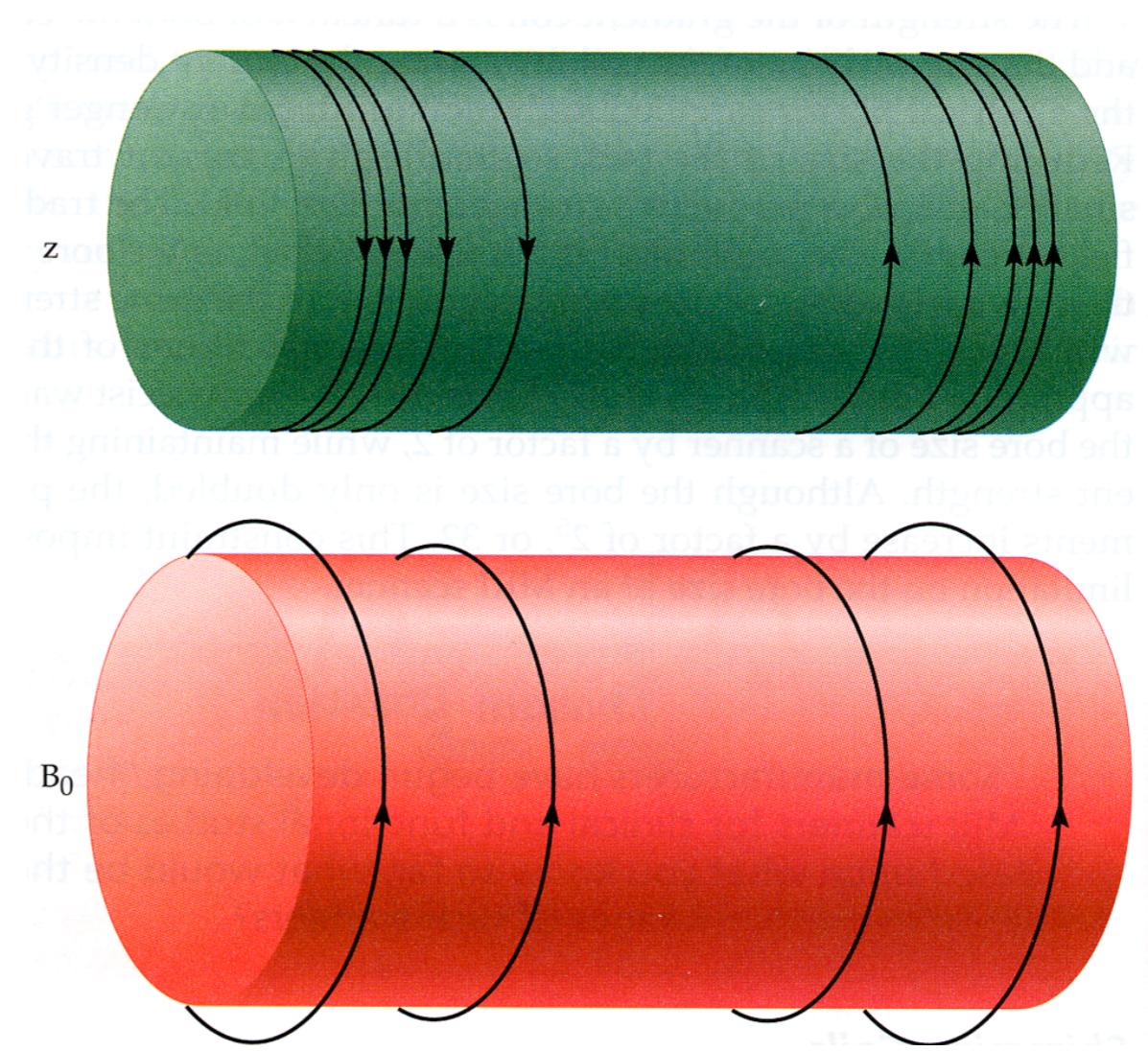
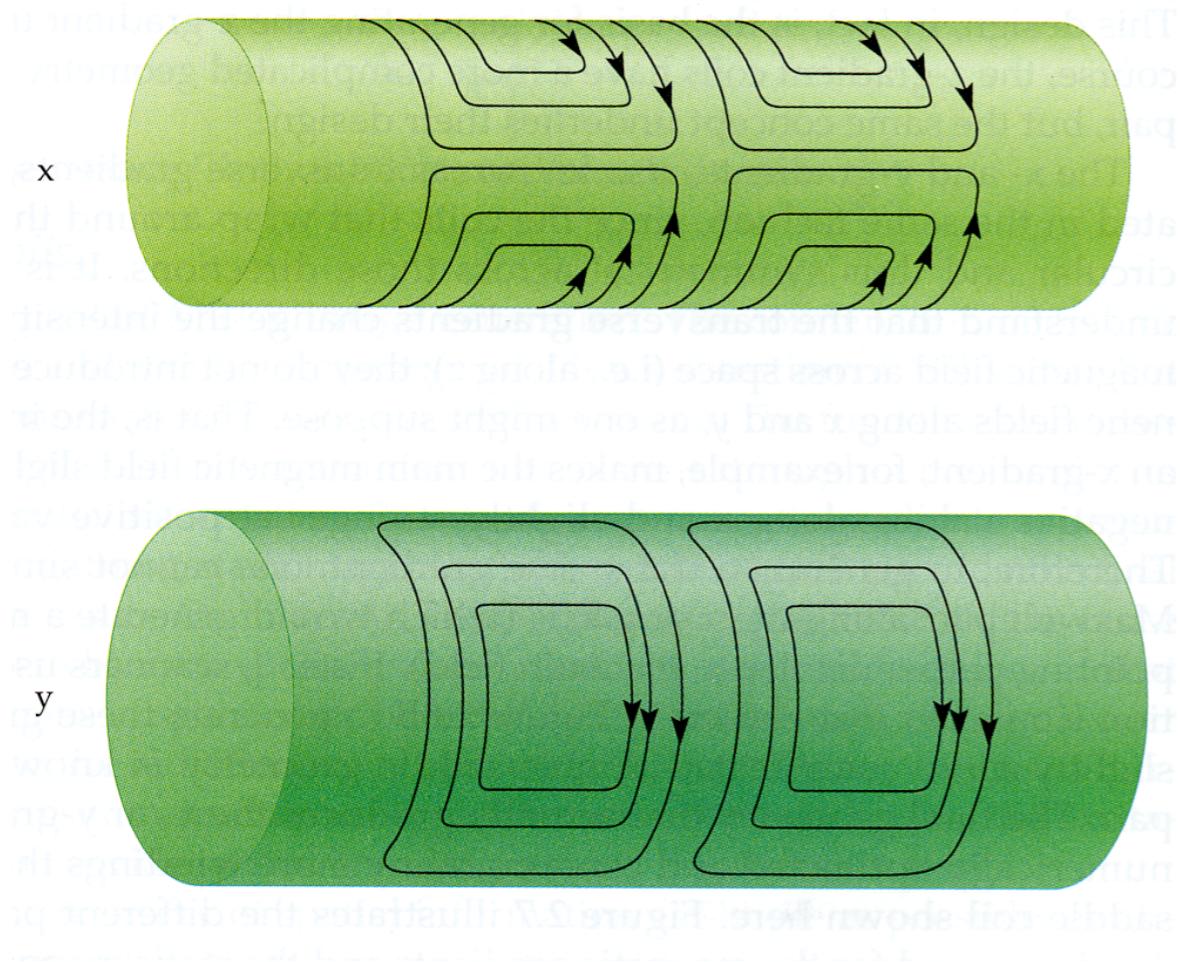
Currents are in opposite directions



1. Field pointing along z
2. Strength linear in z: $B=(0,0,Gz)$

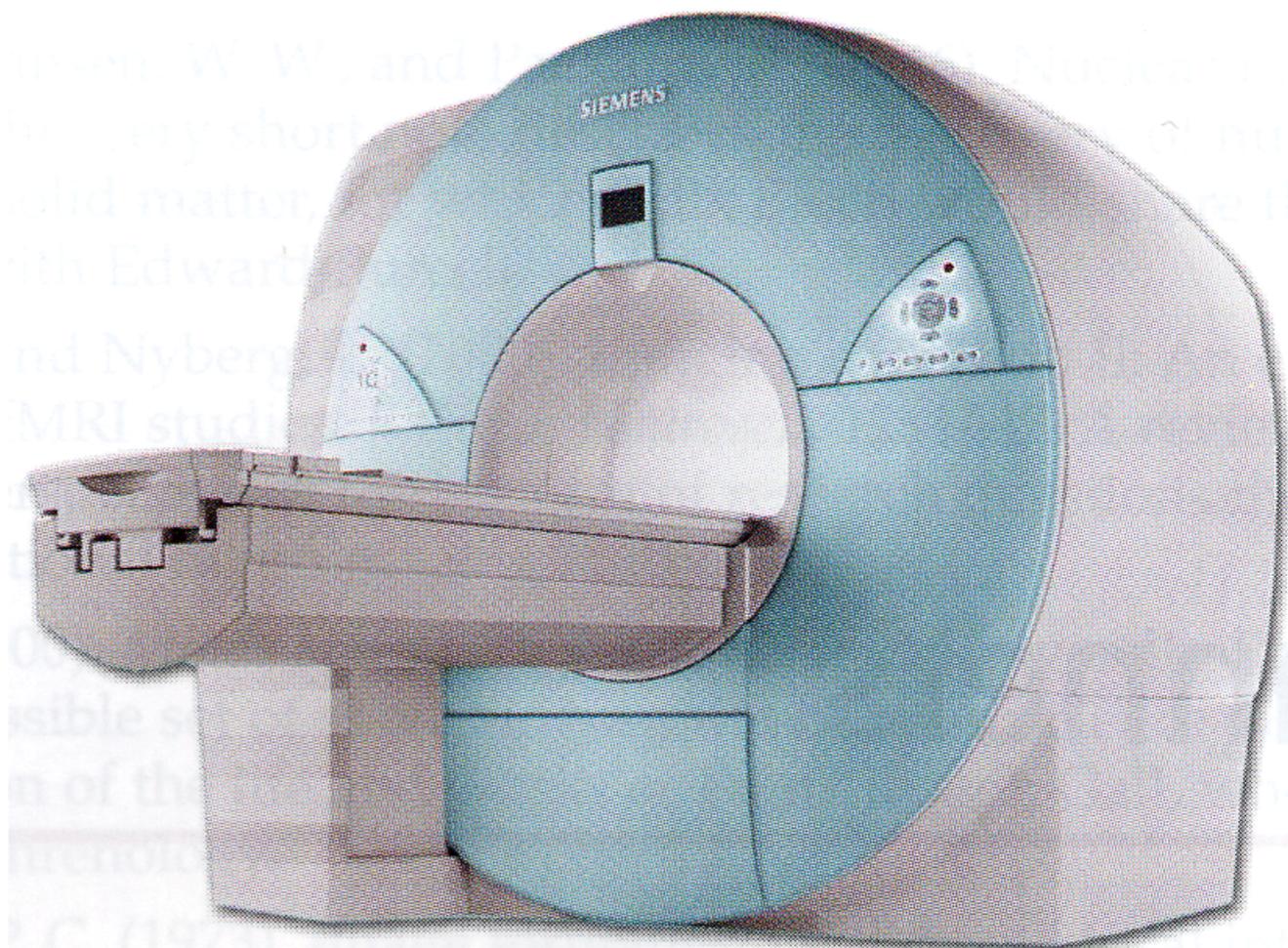
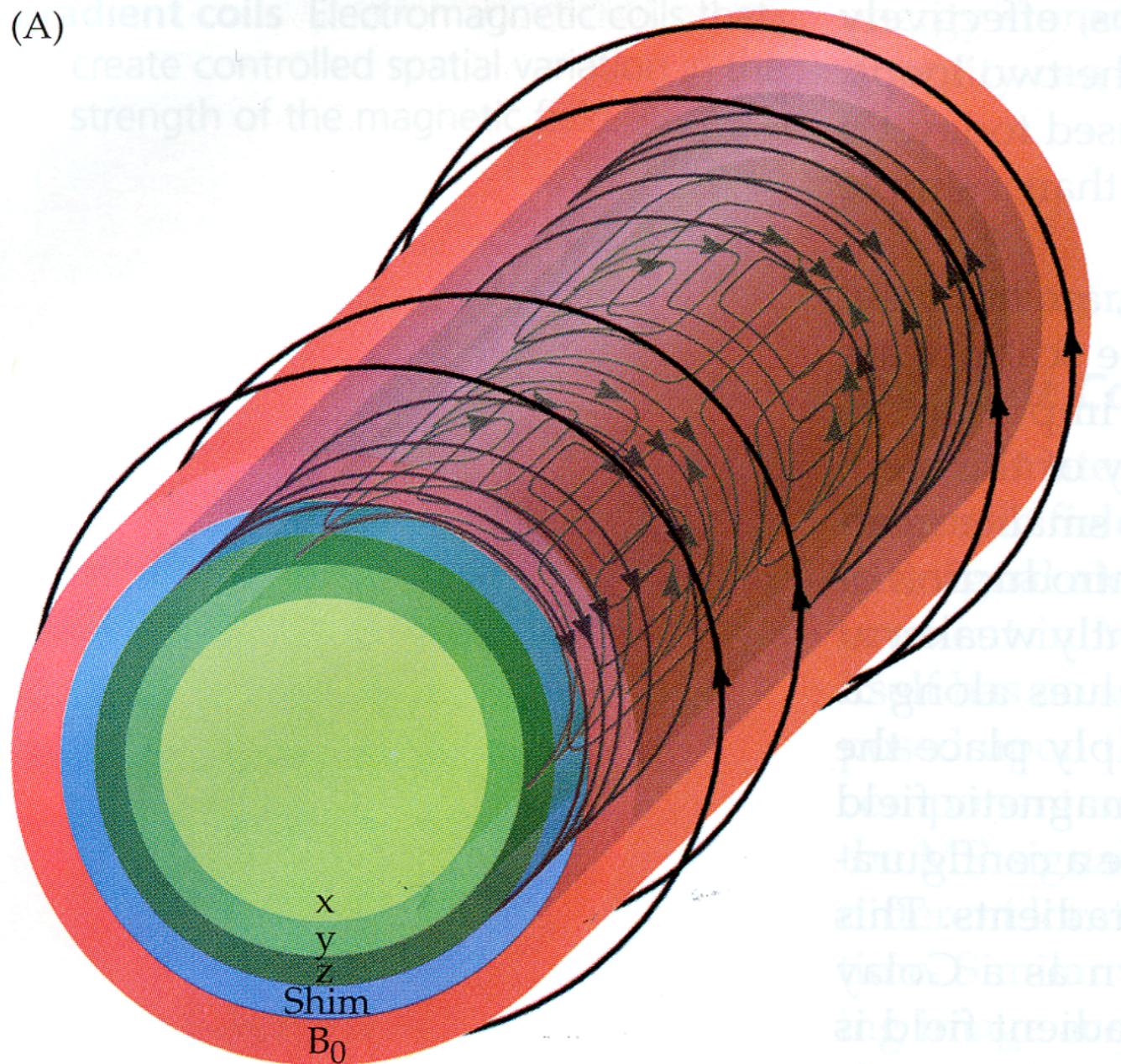
x and y gradients only slightly more complicated

Building an MRI Machine



Main field (B_0) and imaging gradients (G_x, G_y, G_z)

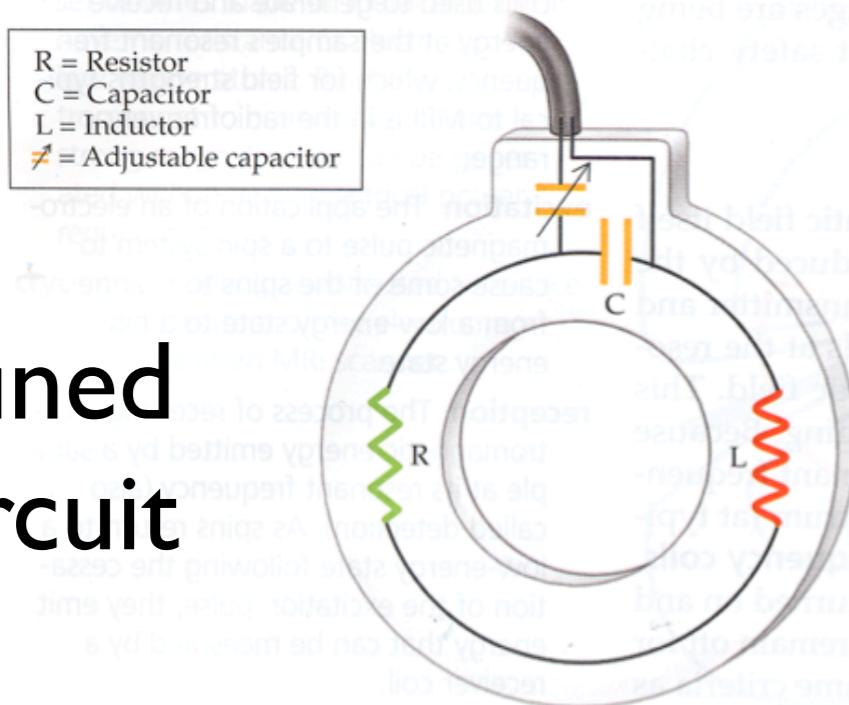
Building an MRI Machine



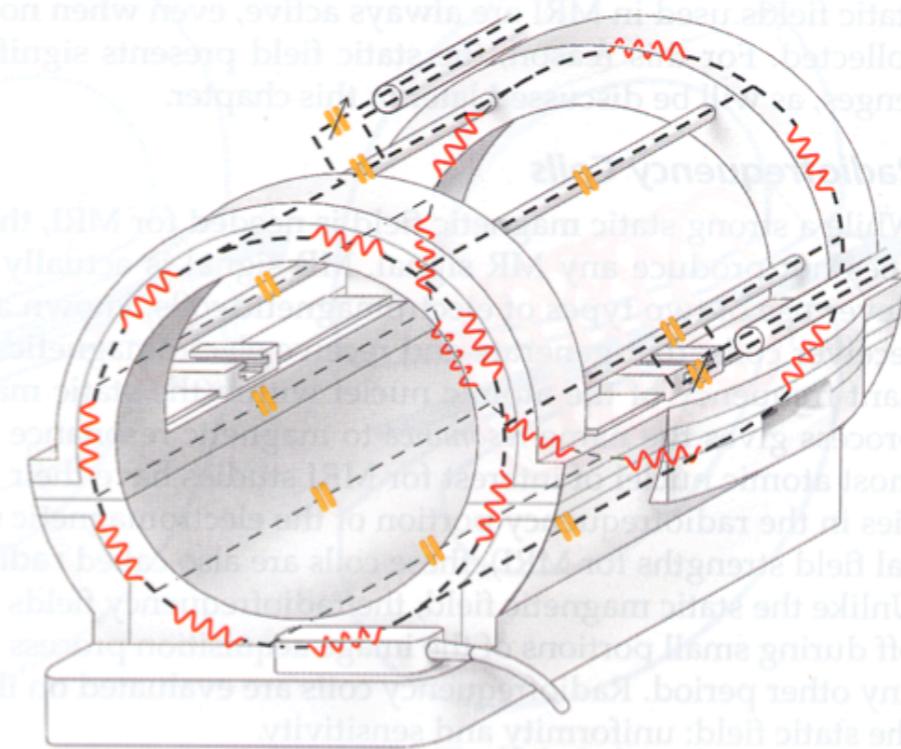
RF Coils

(A) Tuned circuit diagram

R = Resistor
C = Capacitor
L = Inductor
= Adjustable capacitor

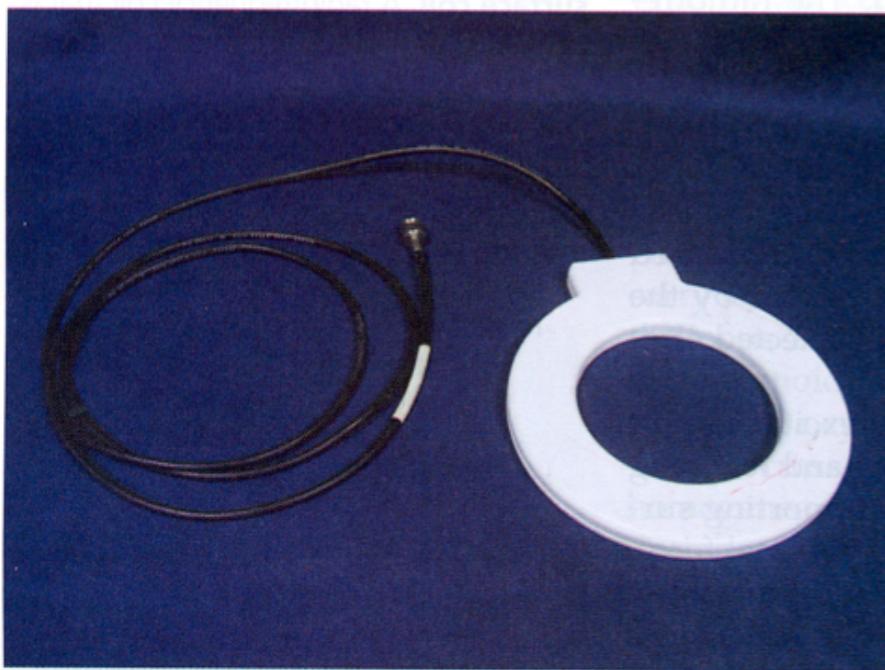


(B)



Tuned circuit

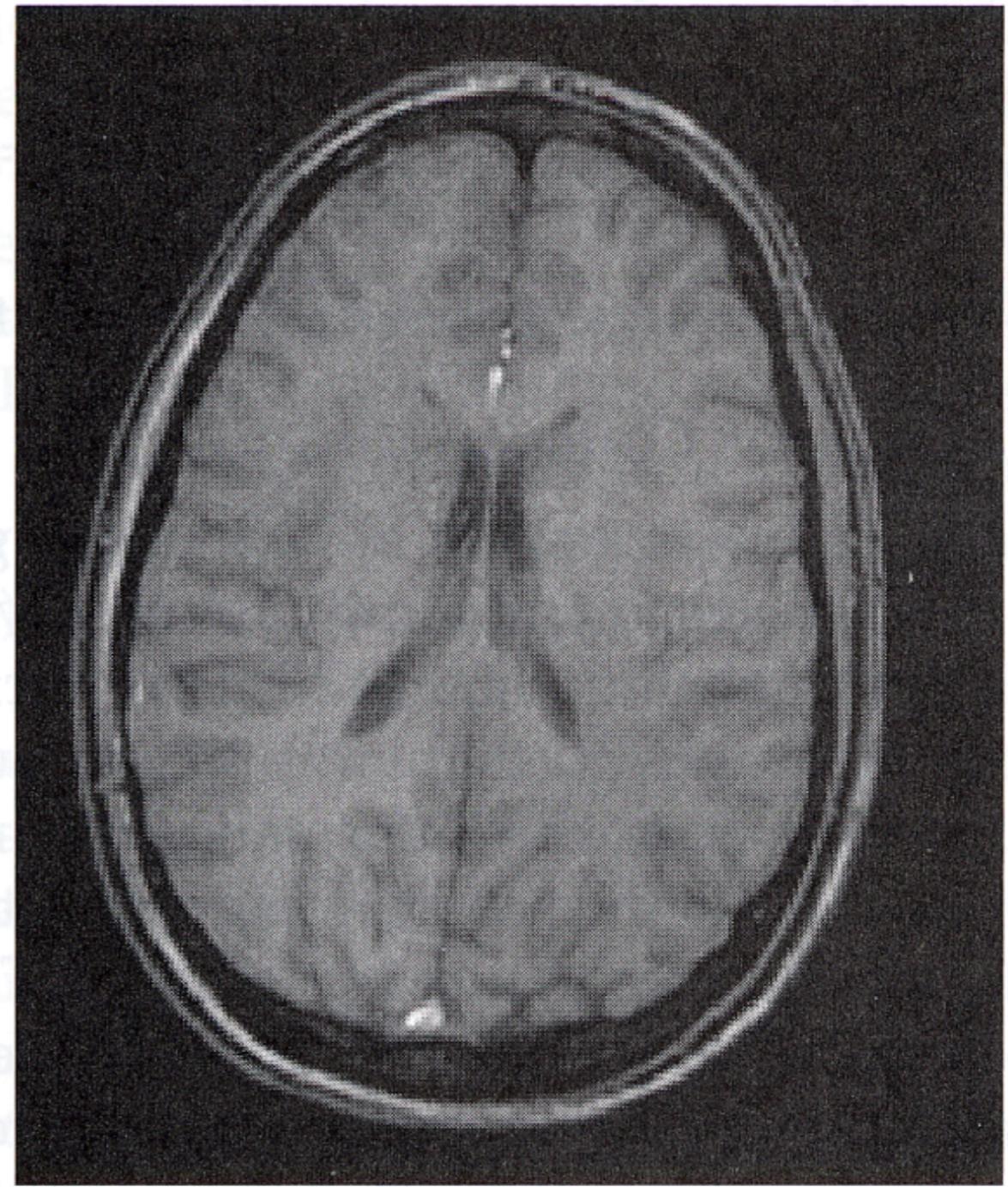
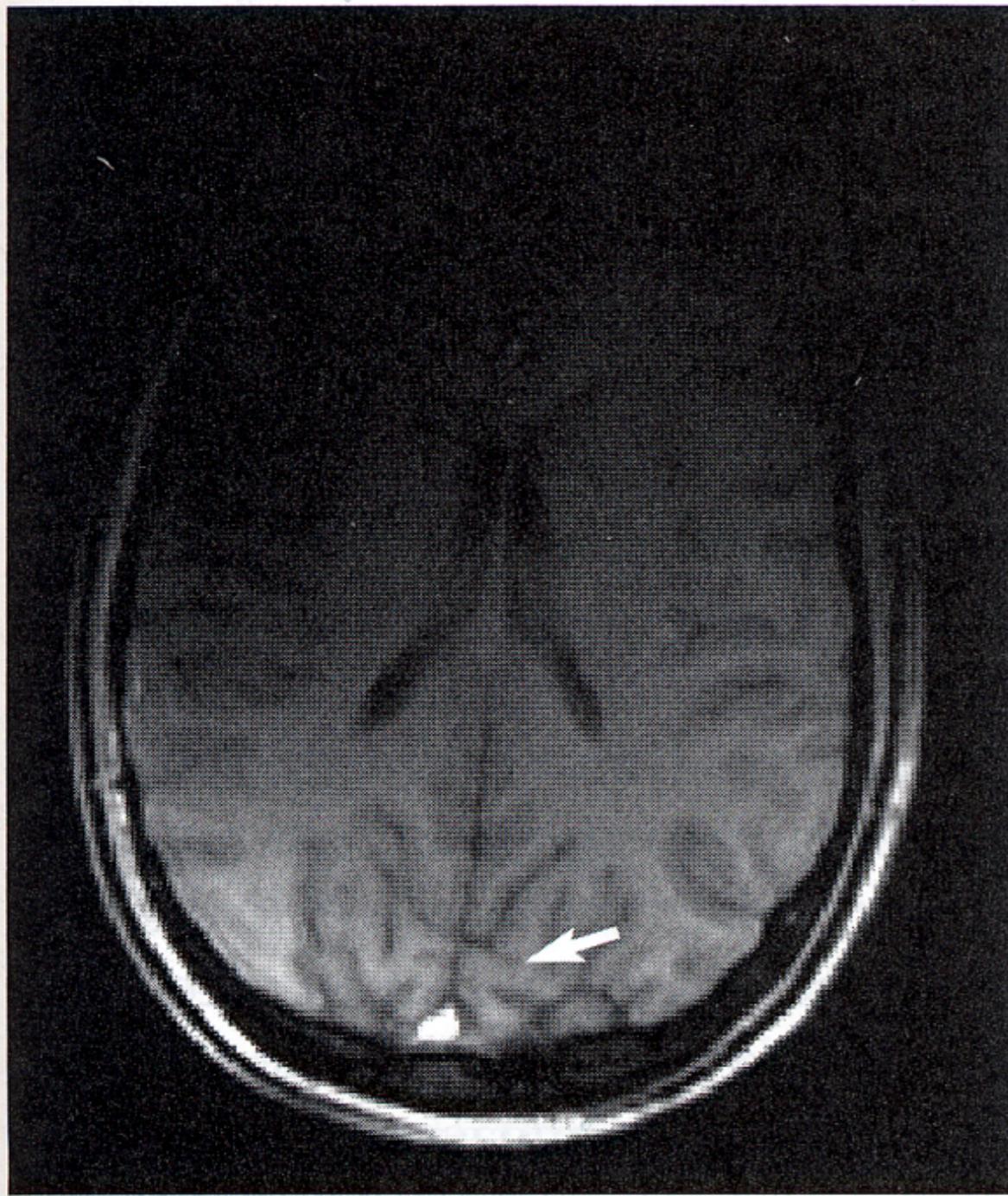
(C)



(D)



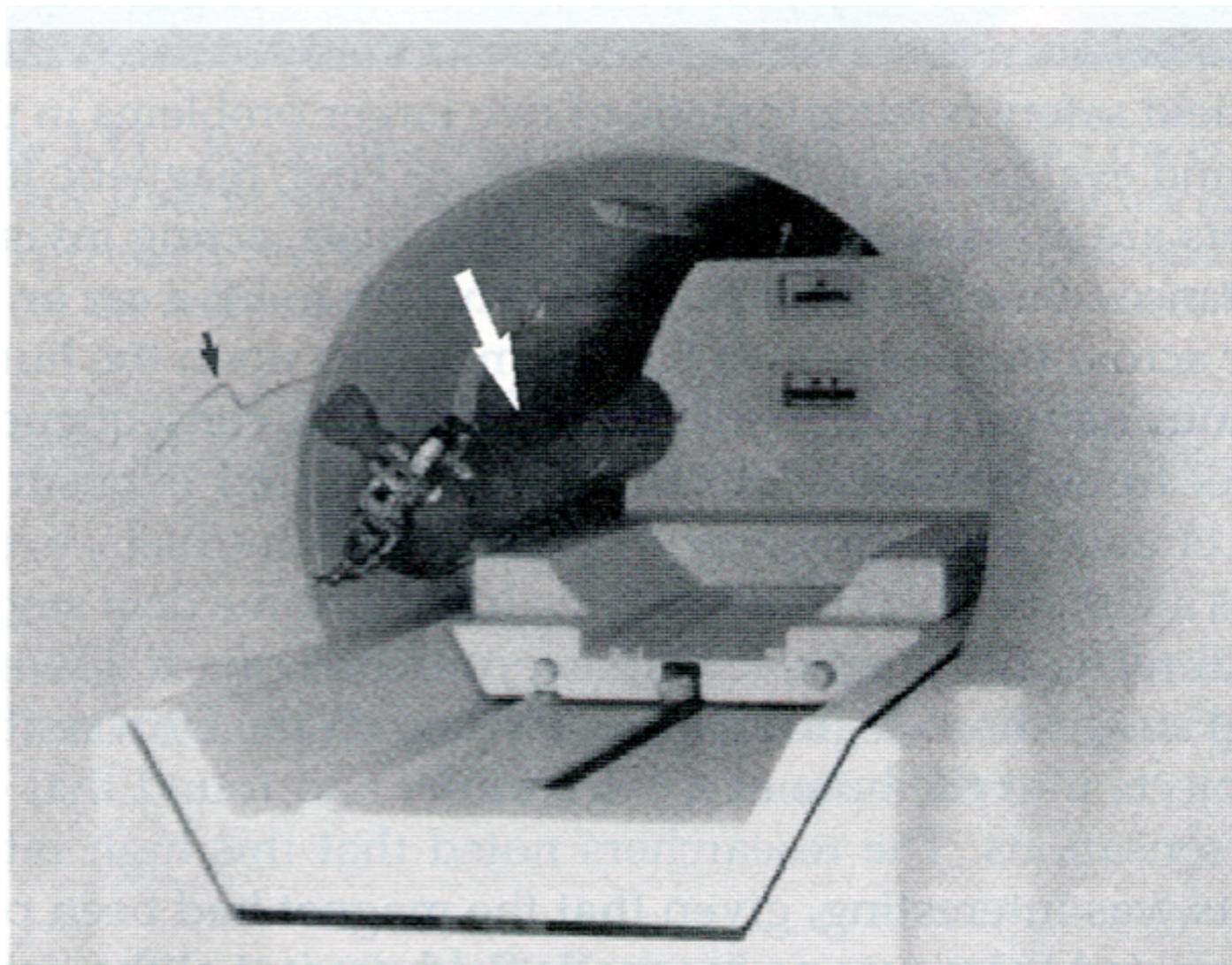
Surface Coils vs Volume Coils



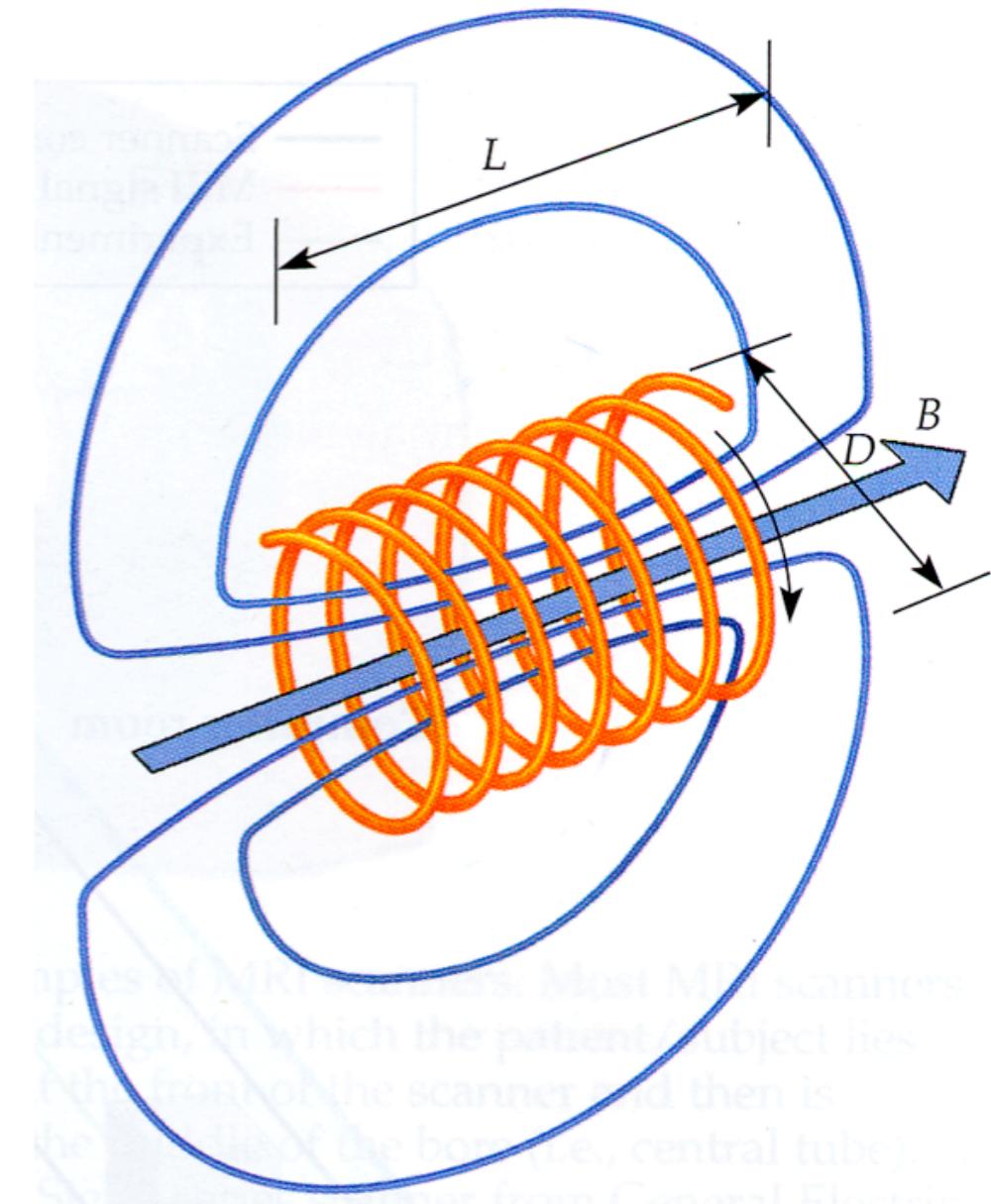
MRI Safety

- MRI is extremely safe
- Risks which can be avoided
 - Projectiles
 - Burns
 - Peripheral Nerve Stimulation
 - Hearing damage (Noise)

Danger of Static Field

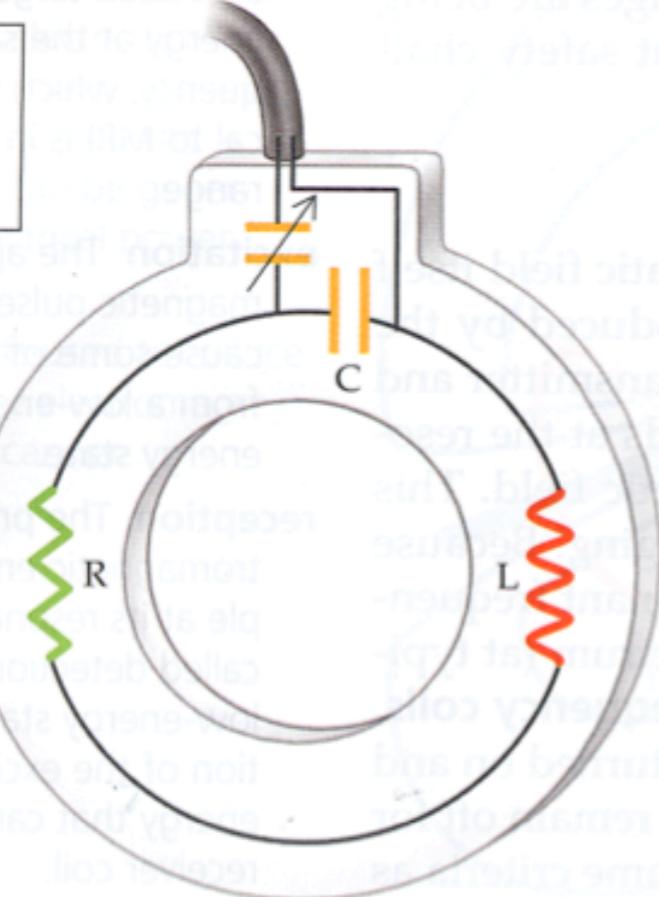


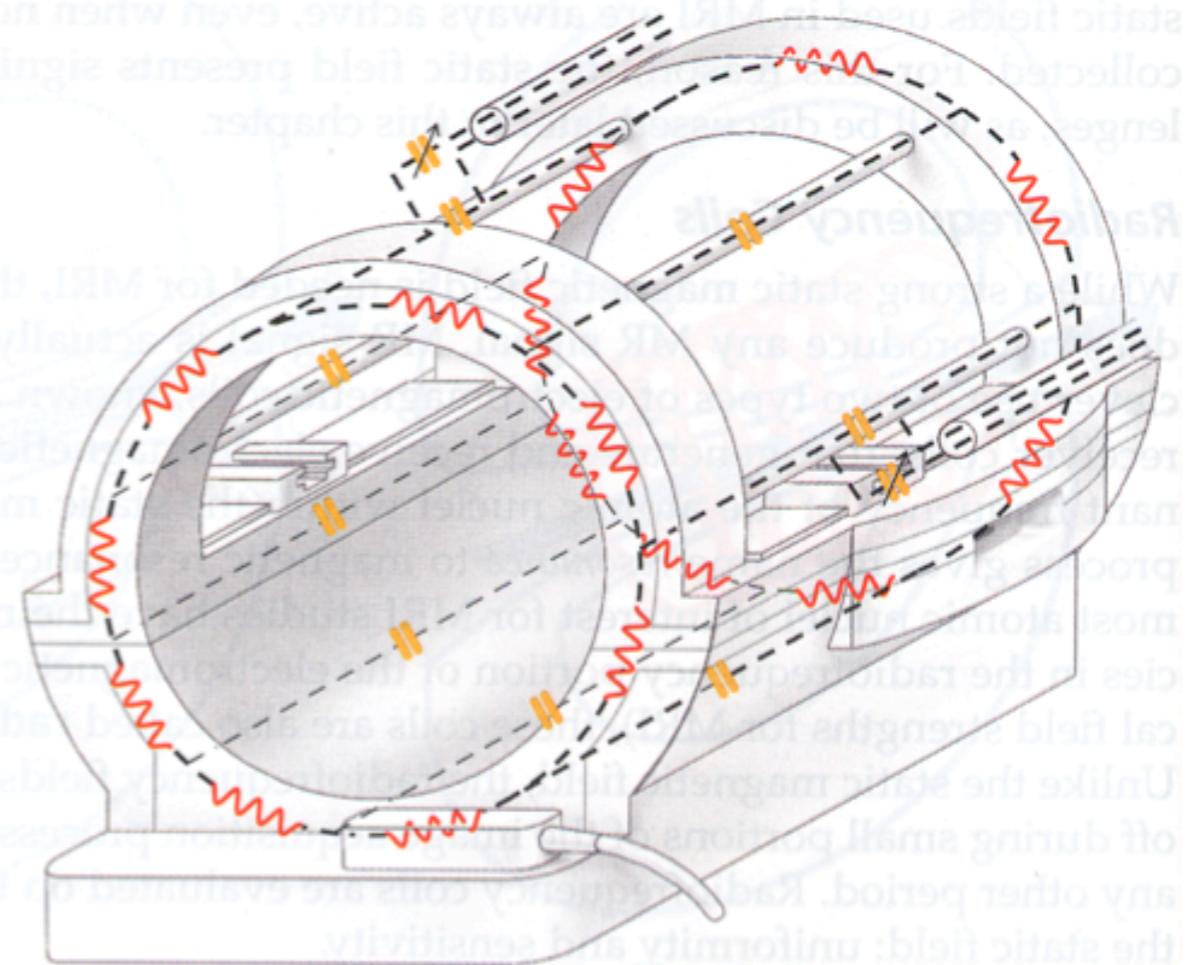
Metal objects become missiles



Main field

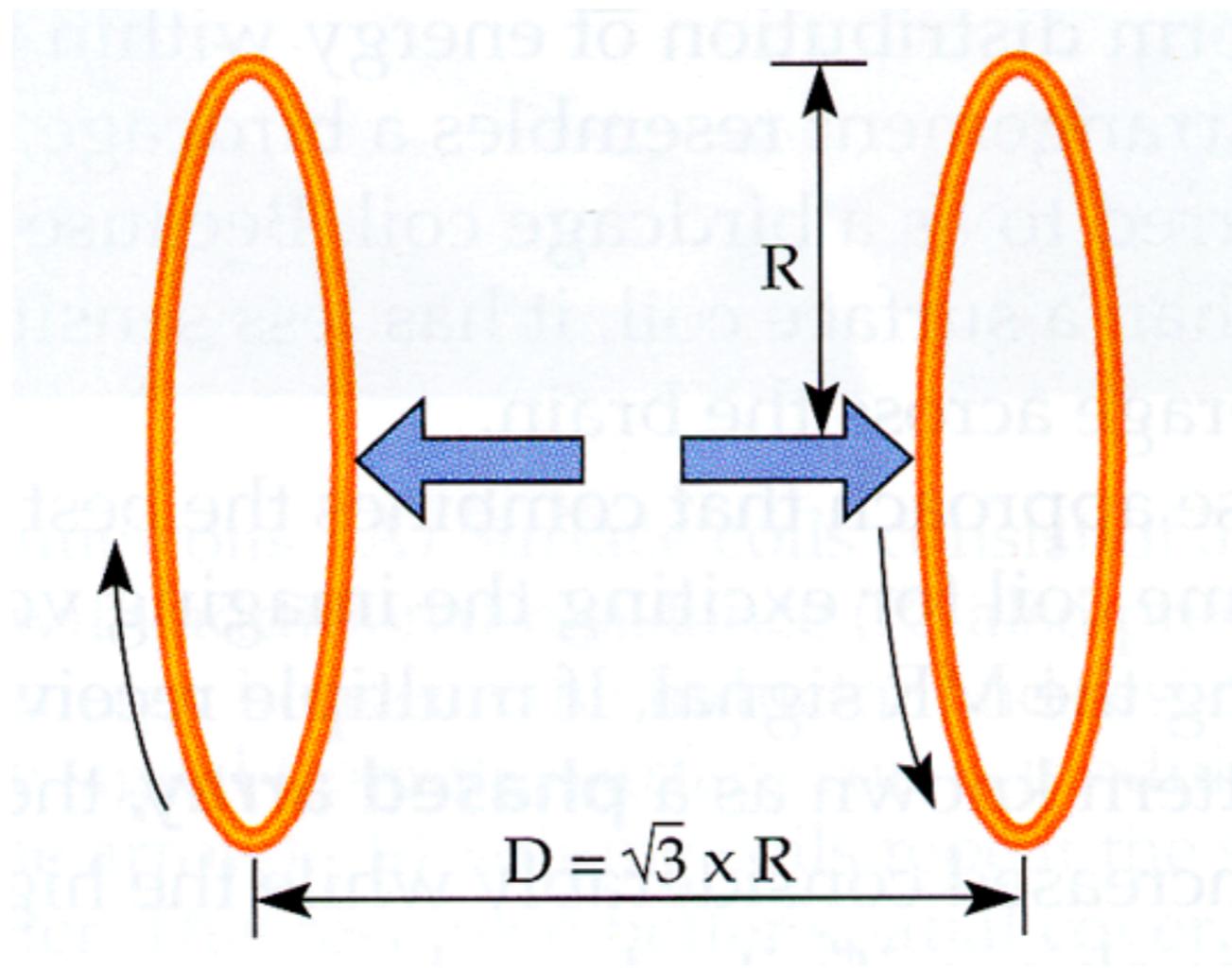
RF Burns

R = Resistor
C = Capacitor
L = Inductor




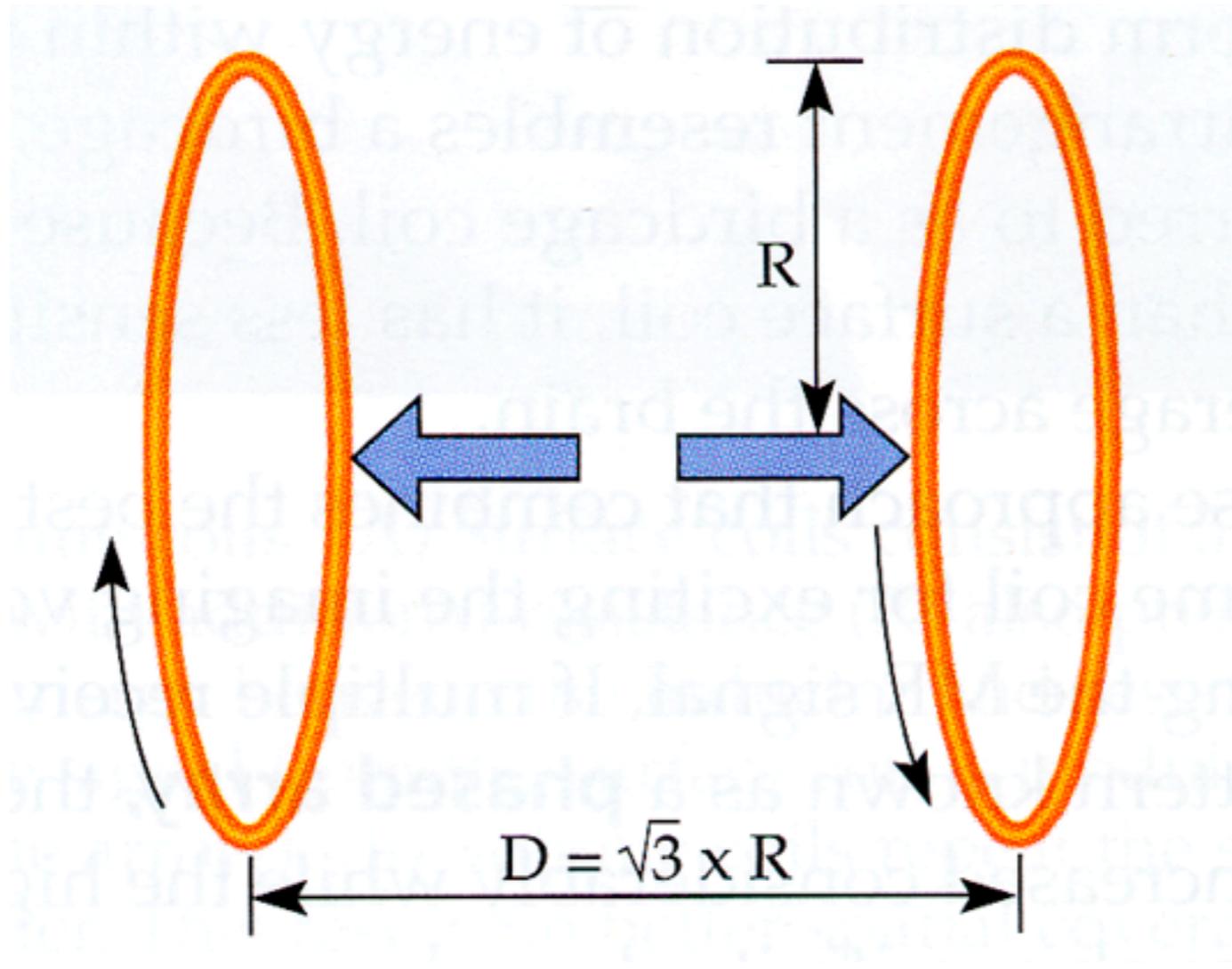
Radio Frequency power absorbed by tissue
(alternating electromagnetic field)
e.g. microwave oven

Peripheral Nerve Stimulation



Switching gradients induces currents in peripheral nerves: tingling, etc.

Noise



Switching gradients produces electric forces which cause mechanical vibration.
EPI is VERY loud $\sim 100\text{dB}$